Geomorphology and palaeoecology of late Holocene floodplain environments in the River Irthing, Cumbria, UK

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Abstract

Palaeochannel development along the middle reaches of the River Irthing valley floor, Cumbria, UK, has been reconstructed *via* a range of palaeoenvironmental techniques. This has enabled the analysis of interactions between the geomorphological, hydrological and ecological components of the floodplain system during the mid to late Holocene. Geomorphological mapping, surveying and lithostratigraphic analysis of palaeochannel fills along a 2.5 kilometre reach of the valley floor has determined the character of Holocene channel and floodplain evolution and the physical context for palaeochannel habitat development. Chronological controls have been provided by historical map analysis and radiocarbon dating. The River Irthing valley floor experienced net fluvial incision from the Pleistocene-Holocene boundary up until the mid Holocene, while late Holocene floodplain evolution has been characterised by a series of channel avulsion and limited floodplain reworking. Periods of channel incision and planform change have been dated to 2440-1920 cal.BC, 670-970 cal.AD, 1410-1620 cal.AD and the late eighteenth to early nineteenth century AD.

Five palaeochannel reaches with well-preserved organic rich channel fill sediments were selected for detailed lithostratigraphic analyses (by multiple core transects) and plant macrofossil analyses. Channel fills provide evidence of rapid biotic response to channel abandonment and subsequent changes to the physical characteristics and trophic status of the habitat. Hydroseral sequences from aquatic to wetland to floodplain woodland communities and the affects of human activity on palaeochannel development are also evident. The results indicate high magnitude flood inundation significantly affects vegetation succession and highlight the importance of physical processes and the landscape context in determining the characteristics of palaeochannel development. The research emphasises the application of plant macrofossil analysis to organic rich alluvial sediments.

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Chapter One

Introduction

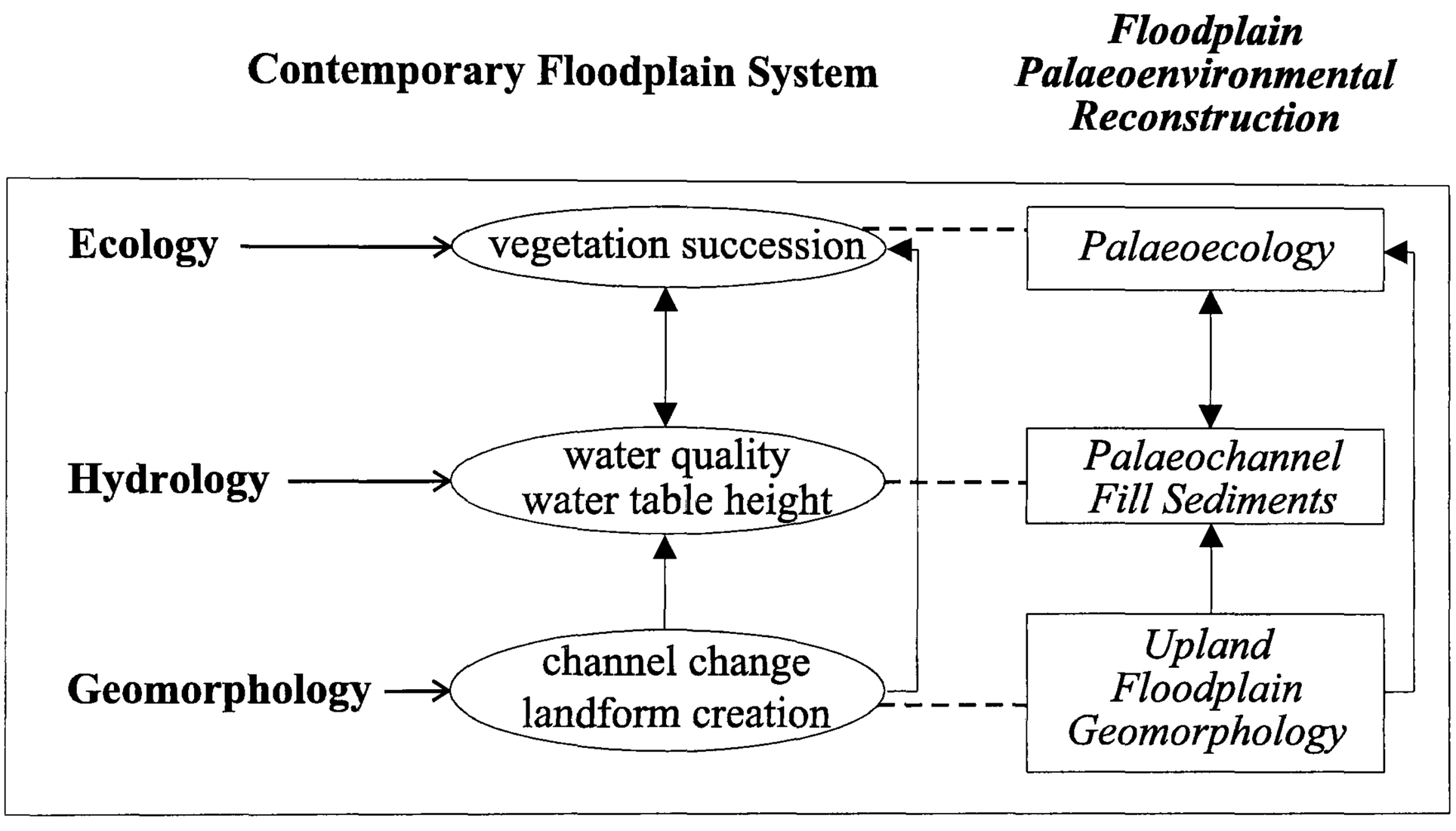
Holocene river valley floors have been a persistent focus of human activity and settlement (Macklin 1999, Moores *et al.* 1999) and hence subject to vegetation clearance, agricultural activity, flow regulation and drainage and channelisation (Petts *et al.* 1992, Gurnell 1995). As a result, concepts surrounding the structure and functioning of floodplain environments were initially derived from research into river regulation, navigation and agricultural and recreational usage. Over the past 20 years, however, it has been acknowledged that floodplains in their natural state are highly diverse environments with respect to both biotic communities and physical landscape features (de Waal *et al.* 1995, Ward *et al.* 1999a).

Floodplain biological diversity reflects the wide range of past and present river channels, floodplain wetlands and environments (Bornette & Amoros 1991b, Pautou *et al.* 1997) and the dynamics of fluvial and sedimentary inputs on the valley floor (Salo 1990, Ward & Stanford 1995). The processes of river channel change and intermediate disturbance in the form of flooding and variable groundwater inputs create a mosaic of habitats, at different stages of vegetation succession (Bravard *et al.* 1986, Bornette *et al.* 1998a, Amoros & Bornette 1999). Diversity is maintained through the process of vegetation community succession and the rejuvenation of communities by flood inundation and habitat creation (Bornette *et al.* 1998a, Ward & Stanford 1995, Amoros & Wade 1996).

Although the potential diversity and complexity of natural floodplain ecosystems has been widely recognised (Petts *et al.* 1992, Hupp & Osterkamp 1996) our comprehension of their structure, functioning and dynamics remains poorly understood (Bornette *et al.* 1998a). Advancements in the present knowledge of floodplain dynamics are necessary for predictions of response to environmental change and the restoration and rehabilitation of floodplain habitats (Henry & Amoros 1995, Ward & Stanford 1995). In particular, up until the 1980s, researchers did not fully address three significant issues. Firstly, ecologists did not account for the importance of geomorphological landforms, processes and disturbance in determining the spatial distribution of floodplain vegetation (Hupp 1988, Salo 1990, Hupp & Osterkamp 1996) and, therefore, were unable to fully evaluate the response of vegetation to physical disturbance, such as flooding and channel change (Wissmar & Swanson (1990). Secondly, as a consequence of the continual degradation of floodplain environments, few examples of

'natural' systems in temperate environments remain, thus hindering the opportunity to both conceptualise floodplain characteristics in their original state prior to human intervention (Amoros & van Urk 1989, Ward *et al.* 1999b) and determine the responses of systems to disturbance events (Brown & Quine 1999). Finally, vegetation has been described as a 'spatiotemporal' phenomena (Jackson 1989), therefore methodological approaches to ecological research should include aspects of both space and time (Sousa 1984). Many researchers have noted, however, that ecological succession, a significant process within floodplain systems, was initially only investigated at the spatial scale (Bravard *et al.* 1986, Amoros *et al.* 1987, Jackson *et al.* 1988).

Figure 1.1 The link between the floodplain system and palaeoenvironmental reconstruction techniques



In order to address the aforementioned limitations, Amoros *et al.* (1987) developed a technique of floodplain analysis which incorporated the spatial and temporal aspects of biotic systems and the influence of physical landforms and processes. This technique advocated the historical and palaeoecological reconstruction of vegetation communities, specifically from former river channels (palaeochannels), and incorporation of valley floor development processes (Fig 1.1). The diversity of valley floor environments can be linked to the physical and ecological processes in palaeochannels and floodplain wetlands; the significance of these being emphasised by the propensity of rivers to inundate and alluviate floodplain topographic depressions during high discharge events (Gilvear & Harrison 1991). Palaeochannel fills can

potentially provide a record of both flood inundation and biotic change. Using this approach, subsequent research has elucidated the impacts of flooding, human activity and channel change on vegetation succession and floodplain diversity (eg Brown 1988; 1999, Amoros & van Urk 1989, Petts *et al.* 1992, Baker *et al.* 1993, Tipping 1994, Singer *et al.* 1996, Baker 2000).

In their discussion of the utility of palaeoecological techniques to reconstruct temporal floodplain vegetation change, Amoros *et al.* (1987) emphasise the importance of *spatial scale*. Ecological processes operate over a range of scales from the microhabitat (riffle scale for example) up to the landscape scale (Frissel *et al.* 1986), and therefore the objectives of palaeoecological research must correspond with the spatial scale at which vegetation communities are represented within fossil data. Jackson (1989) notes that analysis of temporal and spatial patterns of vegetation communities must be undertaken at scales smaller than those reproduced by palynological techniques which incorporate extra regional vegetation data (Brown 1997a). He thus advocates the use of techniques, such as plant macrofossil analysis, which can reconstruct habitat scale vegetation communities (cf. Birks 1980, 2000, Baker & Drake 1994, Singer *et al.* 1996). Due to the advantages offered by plant macrofossil, including species level identification and *in situ* deposition analysis, a number of authors have adopted this approach to reconstruct ecological change and disturbance regimes in floodplain environments (eg. Baker *et al.* 1993, Garneau 1997, Wells & Wheeler 1999, Baker 2000, Pokorny *et al.* 2000).

The palaeoenvironmental reconstruction of floodplain habitats requires a holistic approach (Bravard *et al.* 1997) necessitating the application of geomorphological reconstruction and palaeoecological techniques. In British fluvial systems, upland river catchments are known to be susceptible to a combination of climatic variability and human activity (Lewin 1992, Brown 1997a, Macklin 1999), resulting in complex response mechanisms which manifest as fluvial incision, alluviation, lateral reworking and channel avulsions. However, the analysis of alluvial histories is hindered due to problems with the lack of well-preserved organic sediments for palaeoecological research and the dating of periods of channel change and fluvial activity (Macklin *et al.* 1992a, Ballantyne 1991, Passmore *et al.* 1993, Passmore & Macklin 1997;2000). Recent progress has been made, however, from research on the River North Tyne floodplain (Moores 1998, Moores *et al.* 1999) and on sites within the Milfield basin, Northumberland (Tipping 1998). Furthermore, preliminary investigations in the River Irthing catchment, a tributary of the River Eden, north west England, have located floodplain reaches with well preserved organic floodplain sediments suitable for palaeoecological

analysis and radiocarbon dating (Cotton *et al.* 1999). Palaeoecological records from north west England have predominantly been obtained from upland ombrotrophic bogs (eg Dumayne 1993, Stoneman 1993, Barber *et al.* 1994a) with a small number of records also available from mires and blanket bogs at valley floor, foothill and upper valley side sites in eastern Cumbria, near to the middle reaches of the River Eden (Skinner & Brown 1999). The latter research however was solely focused on the Neolithic period with the aim of assessing regional biodiversity. Assessment of valley floor palaeoecology in northern England and southern Scotland as a whole is limited to work undertaken in the River North Tyne catchment (Moores 1998), the Cheviots (Tipping 1992) and in the Kirtle Water catchment, south west Scotland (Tipping 1995a).

With the exception of research undertaken by the present author (Cotton *et al.* 1999), neither the River Irthing catchment nor the Eden basin as a whole have been investigated with respect to either Holocene valley floor development or contemporary channel and floodplain geomorphology. Research has been undertaken into the alluvial histories of catchments to the north of the River Irthing catchment at Kirtle Water (eg Tipping 1995a), to the south in the Bowland and Howgill Fells (eg Harvey *et al.* 1984, Harvey 1985, 1997) and to the east within the River Tyne catchment (Macklin *et al.* 1992a, Passmore *et al.* 1993, Rumsby & Macklin 1994, Passmore & Macklin 1997). Overall, assessment of Holocene valley floor vegetation has received little attention in the Eden basin and in the River Irthing catchment. Moreover, archaeological evidence from northern Cumbria suggests major disturbance from the late Iron Age, therefore providing the potential of reconstructing undisturbed floodplain habitats prior to that date. The River Irthing catchment thus presents a unique opportunity to undertake palaeoenvironmental reconstructions of both floodplain vegetation development and alluvial histories.

In summary, the research into contemporary floodplain systems, and the debates surrounding floodplain palaeoenvironmental reconstruction techniques have highlighted the following issues;

1. the importance of ecological succession in former river channels and floodplain wetlands as a process governing the diversity of those floodplain environments
2. the limited amount of research which has applied holistic methods to elucidate spatial and temporal development of floodplain ecosystems,

3. the potential of applying palaeoenvironmental reconstruction techniques to answer ecological questions, specifically those relating to the usefulness of plant macrofossil analysis,
4. the suitability of palaeochannel environments for the analysis of ecological, hydrological and geomorphological change,
5. the rarity of well preserved palaeochannel organic sediments in upland river catchments for palaeoecological analyses and dating of Holocene floodplain evolution,
6. the absence of research along the River Irthing valley floor.

1.1 Research Aims and Objectives

The main aim of this research is to investigate the principal processes and controls of late Holocene floodplain vegetation development, within five palaeochannels at two adjacent sites in the River Irthing catchment, north west England. Reconstruction of biotic change is undertaken with respect to geomorphological and hydrological processes and disturbance regimes, through the application of palaeoenvironmental reconstruction techniques. The main objectives of the research are:

- *The modelling of late Holocene palaeochannel vegetation development, via plant macrofossil analysis, with respect to geomorphological, hydrological and ecological interactions and human activity.*

  Analysis of palaeochannel habitat development will address issues surrounding timescales and the dominant controls of vegetation change and succession. These are compared with contemporary studies and previous palaeoecological research. The impacts of flooding and significance of the channel regime upon the palaeochannel habitat will also be considered.

- *The incorporation of results within the context of mid-late Holocene upland floodplain evolution.*

  Floodplain habitat characteristics and development will be analysed on the basis of observed palaeochannel and terrace development and the chronology of periods of incision, alluviation and channel change, the timing of which will be compared with climate records and evidence for anthropogenically-induced landscape disturbance.

- *As the techniques are novel with respect to palaeoecological and floodplain research, a third objective is an evaluation of the methodological approach, including aspects of plant macrofossil analysis and palaeochannel sedimentological analyses.*

To achieve these objectives and address the research aim, a floodplain stretch of the mid-section of the River Irthing floodplain, incorporating two adjacent sites, Dovecote and Kellwood, has been selected for detailed palaeoenvironmental investigation. This involves the reconstruction of the geomorphological evolution of the valley floor, alongside the analysis of temporal vegetation change and sedimentation processes from five palaeochannel fills.

1.2 Thesis Structure

Chapter 2 outlines and discusses the background literature to contemporary floodplain analysis and techniques of floodplain palaeoenvironmental reconstruction. The issues surrounding the spatio- temporal characteristics of floodplain vegetation, the geomorphology of contemporary and Holocene upland environments and methods of palaeoenvironmental reconstruction are discussed. The link between palaeoecology and contemporary floodplain ecological research are also considered with specific reference to plant macrofossil analysis. Chapter 3 describes the research location, incorporating the physical characteristics of the extended study reach and the regional archaeological, historical and environmental contexts of the River Irthing catchment. Chapter 4 describes the methodological approach to the research including historic cartographic analysis, floodplain geomorphology, palaeochannel geometry and sedimentary analysis, plant macrofossil analysis, organic matter content measurements and radiocarbon dating.

The research results and interpretations of the floodplain geomorphology, historical channel change, sedimentary and morphological palaeochannel analyses and plant macrofossil analysis at the upstream part of the extended reach, the Dovecote site, are described and explained in Chapter 5. The results of the equivalent data for the downstream Kellwood site are described and interpreted in Chapter 6. From the palaeochannel data, models of temporal vegetation development have been constructed for each palaeochannel. Each is outlined and discussed in Chapter 7 which also incorporates the data within the contexts of Holocene upland floodplain development and discusses issues surrounding characteristics and patterns of temporal palaeochannel development as elucidated by the research. Finally, Chapter 8 provides research conclusions and implications for further research.

Chapter Two

Literature Review

The following literature review is organised into four sections. Section 2.1 discusses the temporal and spatial characteristics of floodplain vegetation, including concepts of vegetation succession and the effects of natural and anthropogenic disturbance. Section 2.2 discusses aspects of floodplain geomorphology, including the processes of channel change, floodplain development and methods of reconstructing floodplain environments in upland environments. Section 2.3 considers the conceptual link between ecology and palaeoecology with specific reference to the palaeoecological analysis of floodplain environments. Finally, Section 2.4 outlines the palaeoecological technique of plant macrofossil analysis and considers its utility as a palaeoecological tool and issues of taphonomy.

2.1 Floodplain Vegetation: Temporal and Spatial Characteristics

The diversity and complexity of floodplain vegetation communities result from spatial and temporal variability in external factors such as the flood pulse (Junk *et al.* 1989), physical floodplain characteristics, and ecological patch construction by geomorphological dynamics (Petts *et al.* 1992) as well as the influences of water table depth (Bravard *et al.* 1997), the variability of water sources (Bornette & Amoros 1991b) and internal processes including competition and stress (Grime 1974). Of particular importance in the maintenance of species diversity in floodplain environments is the simultaneous presence of biotic communities at various stages of succession (Amoros & Wade 1996). The concept of vegetation succession is discussed further in Section 2.1.1, followed by a consideration of classifying floodplain habitats in Section 2.1.2. The effect of disturbance on valley floor ecosystems, with specific reference to flooding is addressed in Section 2.1.3, whilst Section 2.1.4 discusses the way the physical characteristics affect floodplain vegetation establishment and succession.

2.1.1 Vegetation succession in floodplain environments

Vegetation succession may be described as the changing composition of biotic communities over a short temporal scale i.e. less than 1000 years (Odum 1997). The original ideas of vegetation succession, developed by Clements (1916), considered succession to be the continual, gradual development of a community until a 'climax' community is reached.

Gleason (1927) countered the work of Clements by relating the floristic changes in vegetation to four factors:

i. destruction by pathogens, herbivores or humans,
ii. species interaction,
iii. changes to the physical or chemical characteristics of a habitat enabling preferential growth for some species,
iv. the invasion and establishment of new species.

For the past 20 years, however, it has been accepted that generalised theories of succession offer only limit insight into such a complex process and that many successional pathways exist (Van der Valk 1981, Miles 1987). Furthermore, it is now considered that succession results from changes in individual species and populations as opposed to communities developing as a whole unit (Miles 1987, Ritchie 1995). Through a critical analysis of Gleason's theory of succession, Van der Valk (1981) expressed the significance of plant propagules in vegetation succession, specifically with reference to wetland habitats. His model of vegetation change was based on species life span, propagule longevity and establishment requirements, the combination of which determined that succession will occur when the appropriate environmental conditions for species in a seed bank are available. Although the utility of Van der Valk's model has been acknowledged, it has also been criticised as it does not address species interactions or the spatial limitations to species organisation (Bornette *et al.* 1994c). The latter is highly significant in floodplain habitats where the spatial limitations to species can relate to a complex array of environmental gradients combined with geomorphological and hydrological processes.

Spatial changes in wetland community vegetation along environmental gradients from open water to dry land are termed hydroseral succession (Rieley & Page 1990). While the mechanics are open to debate (e.g. Wassen *et al.* 1996, Bunting & Warner 1998), the characteristics of hydroseral succession across a valley floor are unique due to the dynamic nature of floodplain geomorphology and hydrology (Lenssen *et al.* 1999). Rivers in temperate upland environments, for example, typically migrate and incise into their valley floors (Macklin & Lewin 1993) giving rise to a series of geomorphological landforms including terraces, oxbow lakes, palaeochannels, depositional bars, back swamps and levees (Brown 1996). These features are spatially distributed such that the younger features typically lie proximal to the contemporary river whereas the older floodplain and channel environments will lie further from the channel (Brown 1997a). Therefore, a mosaic of geomorphological landforms, reflecting the former courses and floodplains of the contemporary river, exists

across a floodplain. The processes involved in the creation of floodplain geomorphological features are discussed in greater detail in section 2.2.

Vegetation succession within former river channels or palaeochannel environments, will proceed according to the mechanisms of terrestrialisation, sedimentation rate, organic matter accumulation, eutrophication and species interactions, and external influences including anthropogenic activity, flood inundation and climatic change (Bornette *et al.* 1994d, Amoros & Wade 1996). Continual infilling of palaeochannels, for example, presents the potential for the development of vegetation through a successional sequence from aquatic community through to woodland (Bornette & Heiler 1994, Pokorny *et al.* 2000).

Since the 1920s it has been acknowledged that the characteristics of succession are determined by the balance between the internal (autochthonous) and external (allochthonous) inputs and processes (Shugart 1990). In the broadest sense, autogenic succession is driven by internal processes moving the community towards equilibrium and mature vegetation communities, whereas allogenic inputs disrupt the system and offset successional trends (Odum 1997). However, as in the floodplain environment, there are a large number of potential changes in external environmental controls that can affect vegetation. It has thus been recognised that more information is required on the effects of allogenic processes on successional rates (Bornette *et al.* 1994a).

Allochthonous fluvial inputs are known to affect the early stages of succession via the transport of plant propagules (Barrat-Segretain 1996, Large & Prach 1999, Barrat-Segretain & Bornette 2000). Walker *et al.* (1986) also stress the importance of seed dispersal mechanisms in the establishment of vegetation communities. Their research verified previous findings which revealed how species producing large numbers of wind dispersed seeds such as willow (*Salix*) and poplar (*Populus*), and could rapidly establish on exposed surfaces and were dominant in early stages of succession (e.g. Johnson & Sasser 1985, Nanson & Beach 1977). Allochthonous inputs such as groundwater or flood inundation are thought to rejuvenate or stagnate succession (Bravard *et al.* 1986, Bornette *et al.* 1994a) however, the temporal scales over which communities are affected or can recover have rarely been considered.

Autogenic successional processes within a palaeochannel can change its trophic status, as nutrient accumulation from perennial species and detritus causes eutrophication (Amoros & Wade 1996) and thus exert a control over species present (Bornette & Heiler 1994). The

variability in nutrient inputs into a floodplain system is determined by the magnitude, frequency and characteristics of overbank sedimentation, backwater flow, and groundwater seepage (Bornette *et al.* 1994a, Amoros & Bornette 1999). The trophic status of vegetation communities can represent successional trends (Bornette *et al.* 1994d) being influenced temporally (Pinay *et al.* 1998) and spatially across a floodplain and along the long profile of the river (Spink *et al.* 1998). Succession is a key process requiring consideration of the evaluation of floodplain environmental change as it responds to, and consequently reflects the nature of disturbance (both natural and anthropogenic) and the character and magnitude of channel mobility (Bravard *et al.* 1997). However, Bornette & Heiler (1994) argue that due to the complexities of floodplain systems, and the absence of natural modern analogues for comparison (Ward *et al.* 1999b) there remain a number of unanswered questions;

- the scale over which temporal vegetation change and succession occur (Bornette *et al.* 1994d),
- the influence and effects of allochthonous inputs, including flood inundation (Barrat-Segretain & Amoros 1995, Wondzell & Swanson 1999),
- the relationship between vegetation succession and the fluvial regime (Bornette & Heiler 1994).

2.1.2 Floodplain classification

To understand the complexities of floodplain environments and the spatially and temporally variable interactions between geomorphological and ecological processes requires investigation of a range of sites spanning different geomorphic settings and at different stages of maturity. Accordingly a system of classification is important for site comparisons, and to find comparable sites for evaluation (Frissel *et al.* 1986).

Frissell *et al.* (1986) developed a hierarchical framework for classification of floodplain habitats in order to incorporate aspects of both spatial and temporal variations. Their classification defined each habitat according to controlling processes, spatial boundaries and the physical capacities of a system. The system is unique in describing the spatio-temporal characteristics of aquatic and terrestrial ecosystems.

Following a similar framework to Frissell *et al.* (1986), Amoros *et al.* (1987) devised a process based classification that combined the geomorphological and biotic elements of a floodplain community, whilst incorporating both spatial and temporal characteristics. They classified communities in terms of 'functional units'. Each unit is part of a functional set comprising of either a spatially defined set of communities, at different stages of succession,

or a temporally defined set comprising of one habitat at different stages of development. Different stages of floodplain ecosystem development, incorporated within a functional set, were classified as the eupotamon (lotic ecosystems), the parapotamon (semi-stagnant water), the plesiopotamon (lentic ecosystem, still influenced by the channel), and the palaeopotamon (lentic ecosystem, little influence from channel). This technique was subsequently applied by Petts *et al.* (1992) in the analysis of the River Trent floodplain in the UK. It enabled the construction of a complete synchronous functional set for the middle reaches of the River Trent floodplain, and a classification template for use in future studies in the same area.

2.1.3 The effect of disturbance on floodplain communities

Consideration of disturbance with respect to vegetation is often used in a negative sense. However, disturbance is an important source of temporal and spatial heterogeneity within natural communities (Sousa 1984). The main forms of disturbance in alluvial environments include flooding, fire, drought, climatic change, climatic extreme events and human activity, all of which can be dominant in characterising community structure (Spink *et al.* 1998). The role of disturbance varies throughout the life span of a species, and of a community structure as a whole. Nanson & Beach (1977), for example, found that disturbance on an Alaskan floodplain had marked implications for species in the early stages of establishment. The disturbance, in the form of rapid sedimentation, dictated the species compositions on the younger floodplain surfaces. Sedimentation rates reduced over time, as proximity to the channel decreased, and consequently the magnitude of disturbance decreased. However, while, the initial disturbance was highly significant in determining species establishment and vegetation patterns it did not prevent the establishment of the floodplain ecosystem, although the research was undertaken over a short time scale, the longer term effects could not be assessed.

The affect of disturbance on floodplain habitats was investigated by Bornette *et al.* (1994d) who observed, from seasonal and interannual observations of vegetation community compositions in the Rhone catchment, that fluctuations at various temporal scales occurred. They concluded that the disturbance regimes created a shifting mosaic of vegetation in the short term but an overall stability across the floodplain on a yearly scale. The response of biota to a disturbance event is variable over time and consideration of the temporal scale at which disturbance is observed is essential (Bornette & Amoros 1996).

2.1.3.1 The influence of flooding

Although the role of flooding in the composition of floodplain habitats is not completely understood, the importance of periodic flood inundation is presently acknowledged (Junk *et al.* 1989, Hupp & Osterkamp 1996, Tockner *et al.* 1999). The major effects of floods are the potential destruction of floodplain species, the creation of new geomorphological features for colonisation, the implementation of tolerance gradients across the valley floor (Wissmar & Swanson 1990, Gurnell 1995), the input and recycling of nutrients (Spink *et al.* 1998) and the reversal of vegetation succession trends (Bornette *et al.* 1994a). Each of these issues is considered below.

High magnitude floods can have significant effects on vegetation. Indeed, the effect of flooding on alluvial woodlands can be such that the destructive effects on individual stands can be used to reconstruct the extent of past flooding (Bedinger 1971). Species of *Alnus* can exist close to river channels due to their high moisture requirements, but cannot survive in areas of the channel scoured by floods (Wissmar & Swanson 1990). Thresholds of biotic response to flooding have been demonstrated by Amoros & Bornette (1996) who found that in frequently flooded ecosystems, vegetation destruction and scour was more probable if inundation velocity was not retarded by the physical morphology and vegetation of a habitat. Hupp & Osterkamp (1985) also found the susceptibility of plants to destructive flooding a major factor in species distribution on a floodplain in Virginia. While Hawkins *et al.* (1997), from analysis of riparian vegetation following a high magnitude flood, demonstrated the importance of evaluating species and site vulnerability to flooding before restoring a wetland habitat. As Walker *et al.* (1986) note, flooding during initial stages of species establishment can result in a high level of seedling mortality for those species ill-suited to high energy conditions. Many floodplain species are adapted to hydroperiods (- the specific length of flood inundation each year cf. Hughes 1997) and changes to the hydrological regime can have a significant effect on the ecosystem (Bren 1993).

Flooding can result in high rates of sedimentation, therefore species with roots in the top of the soil profile must have rapid response mechanisms to survive flood sediment deposition (Hupp 1988). Those species with high growth rates, termed as 'r' selected species, are better adapted for high rates of sedimentation and more prevalent (Grime 1979). Furthermore, inundation can produce environmental gradients relating to nutrient availability and water table depth. As noted by Spink *et al.* (1998) flooding enables both longitudinal and lateral exchanges in nutrients down a river profile. A number of studies of nutrient dynamics in floodplain ecosystems (e.g. Vancleve *et al.* 1993, Bornette *et al.* 1994a, 1998a, Spink *et al.*

1998, Takertert *et al.* 1999) have also revealed the importance of temporal variability in groundwater and, subsequently, vegetation succession.

With respect to external influences on vegetation succession, flooding can be used as an indicator of successional type. Pautou & Decamps (1985) for example demonstrated that rejuvenation and stagnation of vegetation succession occurred in flood-dominated regions whereas succession proceeds where the water table is the main variable. Similar findings were described by Bornette & Amoros (1996) from a 10 year assessment into the rate of succession in frequently flooded habitats. Here, processes of terrestrialisation (signified by changes in vegetation community composition) in frequently flooded habitats were constrained by inundation. Lastly, from investigations of the effects of river incision on flooding and succession across floodplain environments in south east France, Bravard *et al.* (1997) noted that high rates of fluvial incision reduced flood frequency resulting in large proportions of the floodplain being colonised by mature forest. This contrasted with floodplains experiencing low rates of incision and more frequent inundation, characterised by younger successional communities.

In summary, these studies demonstrate the significant influence of flooding through the processes of scour, sedimentation, nutrient dynamics and propogule transport (Amoros & Bornette 1999) and underline the importance of analysis of flood regimes.

2.1.4 The physical environment

The landforms created by channel and floodplain evolution and maintained by the hydrological regime create specific physical templates on which vegetation communities develop (Hupp & Osterkamp 1985, Townsend & Hildrew 1994). Interactions within the floodplain system, however, render it difficult to evaluate the significance of specific physical micro-habitat characteristics, such as temperature, light, flow conditions, and substratum from field data (Armitage 1996), although acknowledging these characteristics is essential when assessing floodplain communities.

Vandenbrink *et al.* (1995) for example, in seeking to determine the importance of substrate characteristics for floodplain vegetation growth found the results of controlled laboratory experiments contrasted with field observations, thus emphasising the influence of other factors within the floodplain system in the controlling of biotic productivity. Records of ecological niche data (e.g. Grime *et al.* 1990, Rodwell 1995) also provide data regarding the substrate characteristics preferable to specific species. Such inter-relations between the biotic

and abiotic elements of a floodplain ecosystem were acknowledged by Bornette & Amoros (1991b) when they used a wide range of physical parameters to classify biotic development within former braided river channels.

Amoros & Wade (1996) discuss the importance of initial channel type and form of abandonment in characterising the vegetation communities of former river channels. They propose that the sinuosity of the original channel determines the rate of change in environmental conditions, with channels of high sinuosity incurring rapid rates of change following channel abandonment due to the greater isolation of the distal parts of the cut off. This hypothesis is based upon research at a limited number of sites, that span a range of short ($<10^2$ years) timescales and which are affected by variable anthropogenic activity. Moreover, research has proved the significance of groundwater inputs (Bornette *et al.* 1998a) which are unrelated to the former channel regime. Additional investigations in different environmental contexts and over longer temporal scales are necessary to test the classification of vegetation change according to the former channel regime and type of abandonment. The effect of an alluvial plug at the upstream end of an abandoned channel has been considered by Bornette *et al.* (1994a). They argue that the extent to which the plug is vegetated can determine the degree of isolation from the main channel, as the energy of the flood pulse is dissipated by vegetation thus reducing the magnitude of allochthonous inputs.

The importance of intrinsic geomorphological controls on vegetation and succession has thus been demonstrated, although direct correlation between biotic characteristics and former regime or channel abandonment type are limited due to the complexity of the floodplain system. Therefore further investigations are necessary to elucidate the influence of former fluvial regimes on floodplain habitats.

2.2 Floodplain Geomorphology of Contemporary and Holocene Upland Environments

The physical environment of the floodplain provides a template on which vegetation communities develop under the influence of both geomorphological and hydrological processes (Townsend & Hildrew 1994). The reconstruction of floodplain environments requires an understanding of the processes of floodplain evolution.

2.2.1 Floodplain development and construction

The construction of floodplains occurs *via* the sedimentation of suspended fine grained sediment from overbank flows and accretion of in channel or bed material (Lewin 1992). Features resulting from sedimentation include levees, abandoned channel fills and alluviated floodplain surfaces while accretion results in the formation of channel bars, and lag deposits (Allen 1965, Lewin 1992, Brown 1997a) although processes may combine to produce composite landforms. Deposition rates and characteristics of floodplain sediments are determined by sediment supply, valley morphology (which controls accommodation space for sediment accumulation), the hydraulics of the fluvial regime (Lewin 1992), floodplain relief and the nature of vegetation cover (Bridge & Leeder 1979). Floodplain sediments therefore reflect changes in these factors and processes, which can result from changes in human activity within a catchment (e.g. Scaife & Burrin 1992, Taylor & Lewin 1997), climatic change (Rumsby 1991, Erskine *et al.* 1992, Rumsby & Macklin 1994, Knox 2000), the hydrological regime (Lewin 1978) and tectonics (Quinghai *et al.* 1996b). Floodplain sediments therefore provide proxy records of environmental change within a catchment system (e.g. Passmore *et al.* 1992, Passmore & Macklin 1997, Macklin 1999) and their analysis thus represented a major advance in palaeoenvironmental investigations of river basins (Butzer 1980).

Channel change occurs when erosional thresholds are crossed under particular conditions of discharge magnitude and timing and sedimentary inputs (Petts & Foster 1985, Brown 1997a). Flood hydrology and sediment characteristics and supply are the main factors in determining the nature of channel change (Harvey 1969, 1977). However, in the long term context, floodplain evolution may create antecedent conditions which also form intrinsic controls over physical thresholds of channel change (Brewer & Lewin 1998). Generally, channel change is manifested as planform change in the context of lateral changes - meander migration, avulsions, cut offs, as described by Erskine *et al.* (1982) and Hooke (1984) and changes to channel parameters and sediment characteristics (Starkel 1991). Following lateral channel change, sections of former river channels or palaeochannels can be preserved on the valley floor, evident from elongate surface depressions on the floodplain surface (Lewin 1992). These are discussed further in section 2.2.3.2.

2.2.2 Upland floodplain development and construction

The legacy of the Devensian glaciation on upland river catchments in Britain was the increase in catchment gradients, the deposition of thick layers of coarse glacio-fluvial sediment and till (Macklin & Lewin 1997) and the creation of hourglass valley morphology

with alternating open and confined valley floor settings (Macklin 1999). Early Holocene development of fluvial systems appears to have been associated with a change from low sinuosity, sediment dominated regimes to sinuous gravel bed rivers (Macklin & Lewin 1986). The main forcings behind these changes were reductions in both peak discharges and sediment supply (Starkel 1991) and floodplain stabilisation with increasing vegetation cover (Brown 1997a). Contemporary and historic upland temperate river channel change has been assessed by Harvey (1977, 1985, 1991) through research on the Howgill Fells, Cumbria. His findings showed that increases in sediment supply result in channel widening, instability and, locally, channel braiding. Conversely narrow meandering streams reflect a reduction or limitation to sediment supply (Harvey 1991, Passmore *et al.* 1993).

Upland systems have the competence to transport coarse Pleistocene sediments (Macklin & Lewin 1986) and the potential to incise and migrate across their valley floors. Initial research linked vertical fluvial incision and the creation of terraced valley floors to glacial melt-water during the late Pleistocene and early Holocene (Passmore & Macklin 1997; 2000). However, recent research has demonstrated that valley floor entrenchment in some upland catchments has been initiated during the past 1500 years, resulting from changes in catchment conditions following anthropogenic landscape disturbance and changes to the fluvial regime (Rumsby 1991, Macklin *et al.* 1992a). Long term trends of incision and floodplain reworking appear to have been variable throughout the Holocene (Passmore & Macklin 1997). Fluvial incision into Pleistocene gravels has resulted in the formation of river terraces across valley floors (Harvey 1985). Terrace edges reflect the limit of lateral erosion and provide an indication of former channel courses, whilst terrace height differences reflect entrenchment into the valley floor and can be used to evaluate the magnitude of incision over time (Brown 1997a, Passmore & Macklin 1997). Terrace heights also provide a relative chronology of channel change and incision (Macklin & Lewin 1986).

Upland fluvial activity, resulting from isostatic rebound following deglaciation, lower magnitude climatic changes and human activity, has continually reworked the valley floors (Macklin & Lewin 1997). The conjecture that there was a reduction in fluvial activity during the early to mid Holocene therefore may partly relate to the absence of preserved valley floor dating to this period due to the continual reworking of floodplain sediments (Lewin 1992). However along floodplain reaches where lateral reworking has not predominated throughout the Holocene fluvial terraces and hence, records of alluviation have been preserved. For example Moores *et al.* (1999) dated river terraces to 5000cal.BC at two sites in the North Tyne catchment, whose presence is linked to an absence of lateral floodplain reworking.

Due to characteristics of sediment supply, valley slope and the flood regime the middle reaches of a river basin are particularly sensitive to external environmental change (Starkel 1991). Middle reaches or piedmont zones can display well defined floodplain features such as terraces and palaeochannels, which reflect periods of lateral reworking, avulsion, incision and alluviation (Brown & Quine 1999, Tockner *et al.* 1999). Active floodplain belts are also found at tributary confluences (Passmore *et al.* 1993).

Although landforms reflecting Holocene fluvial activity are preserved in the middle reaches of an upland catchment, there exists a spatial variability in the controls and responses of floodplain evolution due to antecedent conditions and complex response of channels to catchment environmental change (Macklin 1999). Research in the Tyne catchment, Northumberland, has unveiled diverse spatial patterns of floodplain sedimentation and incision along both the main channel and its tributaries (Macklin *et al.* 1992a, 1992b, Passmore *et al.* 1993, Passmore & Macklin 1997; 2000). Spatial and temporal variability of sediment movement downstream was noted by Macklin & Lewin (1989) and Passmore *et al.* (1993) from observations of sedimentation zones on the River South Tyne. These analyses of channel change revealed the downstream transfer of sediment between these zones which were separated by stable floodplain reaches. This process has also been noted on the River Trent floodplain, downstream of upland tributaries (Brown & Quine 1999), and in two tributaries of the upper Severn catchment, Wales (Taylor & Lewin 1997).

Causes and timing of upland floodplain development

Elucidating the causes and timing of upland floodplain development can be problematic due to the spatial variability of response to environmental change, the lag time between event and response, and the interactions between factors within the catchment which create complex responses (Hickin 1983). Catchment wide investigations, however, have addressed the aforementioned problems enabling a fuller analysis of the timing of fluvial activity (Rumsby & Macklin 1994). Research in upland catchments has thus linked periods of enhanced fluvial activity to the changes in flood frequency and magnitude that result from climatic deterioration (e.g. Higgs 1987, Macklin *et al.* 1992b, Rumsby & Macklin 1994, Brown 1996). Investigations of regional synchronicity of fluvial activity in Britain (Macklin & Lewin 1993), central Europe (Starkel 1991) and the United States (Knox 1995), has seen some workers argue that climate change is the primary forcing mechanism behind channel change for Medieval, post-Medieval and Little Ice Age periods. Investigations have also attributed channel change to human manipulation of the landscape, which initiates significant increases

in sediment supplies (e.g. Tipping 1992; 1998, Howard *et al.* 1999, Passmore & Macklin 2000). It has been acknowledged over the past 10 years that both climatic and anthropogenic factors combine to influence rates of fluvial activity. Macklin & Lewin (1993) from their analysis of regional synchronicity within the Holocene alluvial record, described the causes of fluvial activity as being "climatically driven but culturally blurred". Brown (1997a), however, warns against attributing fluvial activity to either human activity or climate change, as all sediment transport results from climatically driven events and there is a climatic context for every human induced landscape change. Consequently he suggests the use of climate and archaeological proxy records, such as those developed by Barber *et al.* (1994b) and Mauquoy & Barber (1999a; 1999b) from humification and macrofossil analyses of ombrotrophic bogs in northern Cumbria (Section 3.3.2), to correlate with the alluvial record and thus evaluate the relative importance of climatic and anthropogenic forcings on fluvial activity.

2.2.2.1 Holocene floodplain development in upland northern England and southern Scotland

Following the regional ice retreat around 15,000BP (Roberts 1989), the late Pleistocene and early Holocene was characterised by the transport of, and incision into, glacial and periglacial deposits (Harvey 1997, Macklin 1999). Evidence of late Devensian and early Holocene terrace units, which rivers have incised and reworked throughout the Holocene, has been found at numerous sites in northern England and southern Scotland (e.g. Macklin *et al.* 1992a, Tipping 1995a, Howard *et al.* 1999, Moores *et al.* 1999, Passmore & Macklin 2000). The few terrace units in the British uplands dated to between *circa* 7000BC and *circa* 5000BC indicate the period to have been one of channel stability due to the near complete vegetation cover in the uplands (Hooke *et al.* 1990). Within the River North Tyne catchment, Northumberland (Moores *et al.* 1999) the northern Pennines (Macklin *et al.* 1992a) and the Southern Uplands (Tipping 1995a, Tipping 1998), the alluvial records show the early to mid Holocene to be characterised by slow floodplain alluviation. This pattern however is derived from the few well preserved early to mid Holocene terrace and palaeochannel fills and is limited in its scope.

Early evidence for fluvial activity around 5000BC has been found at two sites in northern England. On the lower River Tyne floodplain at Scotswood, this period of incision and alluviation was tentatively attributed by Macklin *et al.* (1992b) to increased flood frequency with an added influence of small scale Mesolithic woodland clearances. The preservation of terrace units along the River Rede floodplain, dated to 5000BC have been attributed by

Moores *et al.* (1999) to low rates of lateral channel migration which limited the reworking of older terrace units. Subsequent to this early activity, an overall increase in fluvial activity in both upland and lowland regions is thought to have begun after 3000BC (Macklin & Lewin 1993).

At Kirtle Water in the Scottish Southern Uplands, dating of the terraces fills has revealed that entrenchment into Pleistocene and Holocene sediments began around 3250BC and continued until the commencement of alluvial peat development from 150BC-400AD (Tipping 1995a). Peat development was followed by floodplain aggradation which left a series of fine grained terrace fills that have been reworked over the past 800 years during a period of complex fluvial activity (between the 12th and 18th centuries). Within the South Tyne catchment, the absence of early Holocene terraces prevented assessment of the beginning of fluvial incision which is known to have persisted until 1430-1100BC (Passmore *et al.* 1993). Subsequently, five periods of Holocene entrenchment and alluviation of the valley floor were identified, culminating in net incision of floodplain sediments (Passmore *et al.* 1993, Passmore & Macklin 2000). Analysis of floodplain evolution at an upland site in the northern Pennines has also revealed a period of dramatic fluvial incision, following limited Holocene fluvial activity. Investigations of floodplain development and fluvial activity at Thinhope Burn by Macklin *et al.* (1992a) revealed a period of entrenchment dated from 240-530AD to 660-980AD, during which the river incised four metres into its valley floor. The period following this incision was one of significant alluviation with the associated palaeochannel, displaying a highly sinuous channel type.

In contrast to the River South Tyne and Kirtle Water reaches, research on the middle reaches of the River North Tyne catchment has revealed the presence of well preserved Holocene terrace units and associated organic rich palaeochannel fills (Passmore & Macklin 1997, Moores 1998, Moores *et al.* 1999). The preservation of terrace units and associated palaeochannel fills has enabled the reconstruction of up to seven dated periods of incision and alluviation on the middle reaches of the River North Tyne floodplain and eight on the River Rede (Moores 1998, Moores *et al.* 1999). These alluvial histories reveal episodic alluviation, and downcutting from 5000BC to the Medieval period (Passmore & Macklin 1997) followed by increased rates of alluviation to the present day (Moores *et al.* 1999). Nearby, upland catchment research in the Milfield Basin, Northumberland has revealed the deposition of 'cut and fill' sediments on the River Glen floodplain, located at the change in channel gradient from the upstream to middle reaches (Tipping 1998). These sediments

include laterally extensive units of peat and overbank minerogenic units representing periods of stability and alluviation respectively.

Work on both the River South Tyne catchment and the Kirtle Water show patterns of floodplain development, including historic floodplain erosion and the predominance of fine sediment alluviation, that has limited the potential availability of organic sediment preservation and thus have inhibited analysis of the chronology of the alluvial histories (Tipping 1995a, Passmore & Macklin 1997; 2000). The mid Holocene entrenchment within the Kirtle Water coincided with a period of climatic deterioration while the more recent fine sediment aggradation has been linked with accelerated anthropogenic activity (Tipping 1995a). In the South Tyne catchment extensive lateral reworking of sediments and valley floor incision which has lowered the ground water levels have also resulted in degradation of organic sediments (Passmore & Macklin 1997). This character of floodplain evolution has recently been attributed to the sensitivity of the system to changes in flood frequency and magnitude (Passmore & Macklin 2000). Similarly, valley floor entrenchment at Thinhope Burn, in the South Tyne catchment, was connected with climatic deterioration, the effects of which were augmented by Iron Age and Romano-British deforestation (Rumsby 1991, Macklin *et al.* 1992a, 1992b).

The different characteristics of Holocene floodplain evolution between the middle reaches of the River South Tyne and River North Tyne, where limited lateral erosion has enabled the preservation of Holocene terraces and organic rich palaeochannel fill sediments, are attributed to variation in valley relief, catchment geology, land use histories and coarse sediment supply (Passmore & Macklin 1997, Moores *et al.* 1999). The preservation of organic rich floodplain sediments in the Milfield Basin enabled palaeoecological analyses that revealed increases in mid Holocene anthropogenic activity, correlated with enhanced alluviation, while subsequent peat development was associated with forest regeneration (Tipping 1998).

The availability of cartographic evidence and dating techniques such as lichenometry (Worsley 1981) and pedogenesis, have aided the analysis of upland channel change spanning the past 500 years. In northern England and southern Scotland accelerated fluvial activity during the past 300 years has been found in the Milfield Basin (Tipping 1998) and in the River Tyne catchments (Macklin *et al.* 1992a, 1992b, Passmore *et al.* 1993, Rumsby & Macklin 1994, Passmore & Macklin 1994; 1997; 2000). The instability has been linked with climatic deterioration of the Little Ice Age and upland land use for agriculture and mining.

From 18th century cartographic evidence for the River South Tyne, Passmore *et al.* (1993) revealed the former presence of locally braided river reaches. These are comparatively rare in contemporary British uplands and are attributed to increased sediment loads and increased flood frequency and magnitude during the latter stages of the Little Ice Age. This historic channel instability continued into the early 19th century with the input of fine sediment from upland metal ore mining, which impeded vegetation growth, preventing the stabilisation of channel bars and banks. Periods of increased flood frequency and magnitude in the River South Tyne catchment have been identified by Macklin *et al.* (1992b) by lichenometric dating of coarse flood sediments. The dates revealed a cyclic period of high flood magnitudes during 1780 to 1820, 1840 to 1880, and 1920 to 1950. Combined analysis of flood frequency, channel instability and climatic data by Rumsby & Macklin (1994) revealed three cycles of fluvial activity related to atmospheric circulation patterns. These cycles included; large flood return periods resulting in channel incision, moderate flood magnitude return periods resulting in lateral channel instability and floodplain aggradation, low rates of fluvial activity. Conversely, evidence for historic fluvial activity at sites within the North Tyne catchment has been limited. The combination natural levee creation, from increased alluviation, and the anthropogenic construction of flood embankments have resulted in a confined active channel zone and limited channel change (Passmore & Macklin 1997, Moores *et al.* 1999).

The examples of upland Holocene floodplain development discussed above highlight a number of problems and limitations to floodplain palaeoenvironmental investigations. Primarily, the characteristics of floodplain evolution are highly variable across northern England and southern Scotland, therefore no 'single' model can be used to describe and explain upland floodplain evolution (Lewin 1992, Brown 1997a). More extensive investigations are required in order to further elucidate and understand the characteristics and forcings of upland floodplain development (cf. Howard *et al.* 1999). Secondly there is an issue surrounding the chronologies of alluvial histories. Well preserved organic floodplain sediments are rare due to the reworking of valley floors and water table lowering with fluvial incision. More extensive data are therefore necessary in order to elaborate upon the temporal aspects of floodplain development and analyse the timing of fluvial activity with respect to proxy records of environmental change (Brown 1997a). Finally, the rarity of organic floodplain sediment in upland catchments has restricted the amount of palaeoecological research that can be undertaken.

2.2.3 Reconstructing Holocene channel and floodplain environments

2.2.3.1 Historical channel change

Analysis of recent historic channel planform changes and floodplain development benefits from the availability of documentary evidence in the form of maps, aerial photographs, and more recently remote sensed and satellite data. These data sources can indicate both temporal and spatial characteristics of channel change (Hooke & Redmond 1989). In Britain the 1st Edition Ordinance survey maps were published in the mid 19th century, and hence there is countrywide data available which spans the past 150 years. In certain localities older maps are available; for example, Large & Petts (1996) used maps dating back to the 17th century in their analysis of historical river channel change along the River Trent.

Aerial photographs can be used to supplement map data and may potentially reveal high quality geomorphological information, such as terrace edges and palaeochannel forms, which can be used to analyse floodplain geomorphology and identify areas of fluvial activity (Brown 1997a). In addition, a temporal sequence of aerial photographs can reveal short-term changes in channel and floodplain geomorphology. Marston *et al.*'s (1995) analysis of aerial photography of the River Ain, France dating from 1945 to 1991, revealed channel metamorphosis from a braided to single thread meandering river system.

Problems associated with the utilisation of older maps include a variable accuracy of scale and depiction of geomorphological features as techniques of surveying and cartography have changes over the past 300 years (Lewis & Lewin 1983, Hooke & Redmond 1989). Variable accuracy of maps can reduce their comparability, and provide a false image of channel change and metamorphosis. Passmore *et al.* (1993) for example, in their assessment of the representation of geomorphological features on mid 1970s OS maps along the River South Tyne found the number and extent of channel bars to be under-represented. Furthermore, historic and early OS maps are subjected to interpretation during surveying whereby the accuracy and representation of channel bar forms may be dependant upon flow stage. Analysing rates and characteristics of channel change via documentary data is also problematic in the event of irregular channel change as found in braided systems (Hooke & Redmond 1989). Macklin & Lewin (1989) for example found difficulties in the assessment of morphological change along the River South Tyne due to the tendency of the channel to avulse and bifurcate. Finally, although superimposing channel courses extracted from maps enables evaluation of floodplain evolution, caution is recommended when assessing timing as there is a time lag between the surveying of a river course and the publication of the map (Lewis & Lewin 1983).

2.2.3.2 *Floodplain palaeochannels: utility, sedimentation and stratigraphy*

Meander cut-offs, channel avulsion and the rationalisation of braided reaches (Erskine *et al.* 1982), result in the formation of palaeochannels which, over time, infill with sediment from allochthonous and autochthonous sources (Brown 1997a). The rate and characteristics of infilling are dependent upon distance and elevation to the main channel, catchment sediment supply, the surrounding and *in situ* vegetation, water table height and flood frequency and magnitude (Passmore & Macklin 1997, Moores 1998). Moreover, the style of channel abandonment can impact upon palaeochannel infilling (Brown 1997a). Palaeochannel fills can record changes in fluvial regimes and, in the case of autochthonous organic material, can be used for palaeoecological analyses.

Organic Palaeochannel Sediments

Channel cut offs and avulsion give rise to oxbow and ribbon lakes and flood basins, all of which enable the accumulation of fine organic sediments (Brown 1997a). These waterlogged environments provide anaerobic conditions within which organic remains, including plant matter, wood, seeds and pollen, can be preserved (Amoros *et al.* 1987). Moreover, the deposition of organic sediment can create an impermeable layer within palaeochannels resulting in a persistent high water table, or perched aquifer (Brown 1997a). Since hydroseral succession (which provides a proxy indicator of fluvial activity and environmental change- Section 2.1) occurs in floodplain palaeochannels and wetlands, organic sediments provide ideal material for palaeoecological analyses (Brown 1988). Radiocarbon analysis of organic rich channel fills also facilitates dating of sedimentation and ecological change although well-preserved organic fills however are rare in upland environments due to the continual reworking of valley floor sediments during the Holocene and lowering of water tables following vertical fluvial incision (Lewin 1992, Tipping 1995a, Passmore & Macklin 1997, Macklin 1999). Furthermore, inaccuracies in radiocarbon dating can occur following contamination of organic sediments by allochthonous inputs (Brown 1997a).

Interpretation of palaeochannel stratigraphy and sediments

The use of palaeochannel fills for palaeoecological analyses and radiocarbon dating necessitates an understanding of the complexities of floodplain sedimentation. In temperate floodplain environments a diversity of floodplain sediments exists including overbank deposits (suspended sediment, organic fills, laminated flood clays), channel deposits (aggradation deposits, sand plugs), lacrustine deposits and colluvium, all of which potentially can be distinguished via analysis of their characteristics (Lewin 1992, Brown 1997a). Two

aspects of floodplain sediments are used to reconstruct former depositional environments; sedimentary characteristics such as grain size, colour and organic content (Jones 1999) and sedimentary structures such as bars, scrolls and levees (Brown 1997a).

With respect to palaeochannel fill sediments, following channel abandonment former river channels can infill with sediment *via* overbank sedimentation resulting in an array of sedimentary units representing variability in temporal and spatial sedimentation and depositional processes. The processes of palaeochannel infilling were originally believed to relate to particle size sorting which produced a vertical fining upwards sequence i.e. from coarse lag deposit to coarse sand up to overbank silts and clays (Brown 1997a). Allen (1965) also linked palaeochannel infill sequences with the nature of channel abandonment. Neck cut-offs, for example, were believed to possess a sediment plug of bed material at the upstream end with finer grained sediment downstream, whereas in chute cut-offs, bed load predominantly infills the former channel followed by overbank sedimentation when the palaeochannel is disconnected with the river. However, recent research has shown that channel fills reflect changes in allochthonous and autochthonous inputs, therefore the nature of abandonment and former channel type are not the sole determinants of infill characteristics (Bridge 1985, Brierley 1991). Research into historic channel fills on the Hunter River floodplain, Australia, for example, revealed a change in the upper part of the alluvial sequence following an increase in catchment flood sediment loads, grading to the deposition of coarser flood sediments during high flow events (Erskine *et al.* 1992).

With regard to the effects of flood frequency and magnitude on palaeochannel infilling, palaeochannels form depressions in the floodplain surface through which flow is preferentially re-routed during high discharge events (Gilvear & Harrison 1991) thus providing accommodation space for the deposition of sediments during overbank flows (Erskine *et al.* 1982). Within channel fills, inundation events can create erosional contacts with lower sediments, sometimes followed by low energy ponding during waning floods, or form discrete coarse layers and may thus be used as palaeoflood indicators (Baker *et al.* 1983). Assessment of flood horizons in upland catchment palaeochannel fills can be used to provide estimates of changes to flood frequency and magnitude and identify large flood events (Knox 2000).

The inference of depositional processes from the characteristics of floodplain sediments has been enabled by contemporary sediment transport studies. These have developed relationships between velocity and sediment size (such as the Hjulstrom curve), whereby if

velocity and bed material are in equilibrium, the grain size of floodplain sediments will reflect former fluvial depositional processes (Miall 1978, Baker *et al.* 1983, Brown 1997a). Furthermore, analysis of sedimentary structure and boundaries ascertains whether sediments were deposited when the channel was active, such as the inclined stratigraphic units found on point bars, or deposited following abandonment, such as overbank sediments (Bridge 1985). Investigations into depositional processes and the characterisation of sedimentary fills are essential in the palaeoecological analysis of floodplain sediments in order to ascertain the taphonomy of fossil remains (see Section 2.4.4).

In order to provide a method of describing and interpreting floodplain sediments, Miall (1978) developed a coding system which classified alluvial sediments of the basis of broad sedimentary groups and sedimentary structures. A specific depositional environment or fluvial feature was thus attributed to each classification or 'facies' code. Miall's facies codes are a useful aid to the description and interpretation of alluvial sediments (Lewin 1992). Following the development of a coding system for alluvial sediments, facies successions have been derived in order to model the development of alluvial sequences for specific channel types (Miall 1973, 1978). The use of facies sequences has however recently been criticised as the models are limited in their spatial and environmental scope (Bridge 1993, Hickin 1993). With reference to upland floodplain environments, for example, no facies model exists for wandering gravel bed rivers (Hickin 1993), moreover, little is known about the sedimentary facies or alluvial sequences of palaeochannel fills (Bridge 1985). Problems of limited data on palaeochannel fill sequences has been cited with reference to the criticisms regarding the attempts to link fill sediments and the former fluvial regime of a river (Bridge 1985; 1993). Past researchers working on predominantly geological sediment stratigraphy have developed models on the basis that analyses of channel fill sediments can be used to determine former planform morphologies and fluvial regimes (e.g. Friend 1983, Miall 1985). However, more research is required to evaluate the complexity, patterns and controls of palaeochannel fills for geological, geoarchaeological, geomorphological and ecological research into alluvial sediments (Amoros *et al.* 1987, Brierley & Hickin 1991, Erskine *et al.* 1992, Bridge 1993; 2000, Passmore & Macklin 1997, Alexander *et al.* 1999). Nevertheless, despite the limited number of comparative models for palaeochannel fill sequences, the classification of sedimentary units into lithofacies types is a useful tool for the analysis and interpretation of complex floodplain sediments (Lewin 1992, Starkel *et al.* 1996, Jones 1999).

Despite the potential data available from fluvial structures and characteristics, high resolution data from palaeochannel fills are required to investigate the spatial and temporal

characteristics of palaeochannel infilling due to the potentially complex sedimentation patterns (Hickin 1993, Brown 1997a). Previous research, however, has mainly used two dimensional data which contain insufficient detail for the reconstruction of fluvial processes (Mackey & Bridge 1995). Complex sedimentation patterns, for example, made mapping the contact surface between overbank sediments and avulsion deposits a difficulty in the Bighorn Basin, USA (Kraus & Gwinn 1997). Analysis of sediment structures should ideally account for vertical and horizontal floodplain sediment variability (Bridge 1993).

Palaeochannel geometry analysis

The spatial variability of palaeochannel sedimentation patterns relates to a number of external and internal forcings, including the morphology of the former river bed (Etheridge & Schumm 1978). The development of vegetation communities following channel abandonment is also influenced by palaeochannel form (Hupp 1988). From evaluation of vegetation succession in palaeochannels, many authors attest that the characteristics of succession are affected by the former regime of the channel (e.g. Bravard *et al.* 1986, Bornette *et al.* 1991b, Amoros & Wade 1996). These studies, however, were based upon historic or recent timescales, where documentary or contemporary data regarding fluvial regimes and channel morphology is available. Palaeochannel and floodplain investigations across longer timescales necessitate reconstructions of former channel morphology, in the context of the floodplain geomorphology, in order to assess its influence upon sedimentation patterns and vegetation development.

The reconstruction of a former river bed surface can be undertaken when sedimentary differences exist between channel bed and infill sediments (Erskine *et al.* 1992). The basic form of a former river bed is an elongate depression, the dimensions of which can be compared to those of the contemporary river channel (Friend 1983). From measurements of palaeochannel dimensions on the Murrumbidgee River floodplain, Australia, Erskine *et al.* (1982) observed little change from the present channel and therefore could assume that a similar hydrological regime had created the former channel. However, in channel systems prone to episodic and localised metamorphosis of planform morphology, a temporal and spatial variability of channel type exists along the river profile, therefore palaeochannel morphology on upland floodplain surfaces may potentially reflect different regimes to that of the contemporary channel (Hickin 1993). In addition, due to the complexity of channel types and sedimentation, channel planform cannot be unequivocally inferred from floodplain sedimentary characteristics (Bridge 1985, 1993, Brierley & Hickin 1991, Hickin 1993). Analysis of palaeochannel form requires detailed reconstructions of the former channel bed.

Potential problems arise from the analysis of palaeochannel morphology from the complexities of channel bed morphology as features including chutes, branch channels, crevasse splays (Friend 1983) and tree throws (Brown & Keough 1992) can be difficult to interpret in the absence of complete excavation of floodplain sediments. Furthermore fragmentary survival and post abandonment disturbance, such as agricultural activity for example, can limit the scope of palaeochannel analysis (Passmore & Macklin 1997). In addition, geomorphological features exist in three dimensional form but are usually identified in sedimentological research from two dimensional data (Jones 1999). These difficulties were demonstrated by extensive excavations and contemporary fluvial studies of the Squamish River floodplain, Canada, which established the inaccuracies of using one and two dimensional data for the reconstruction of fluvial forms (Brierley 1989, 1991). Detailed three dimensional reconstruction of former floodplain surfaces have been recommended as a means of increasing accuracy when reconstructing former surfaces (Brown & Keough 1992, Bridge 1993).

2.3 The Application of Palaeoecology to Contemporary Floodplain Ecological Research

To increase the understanding of change in natural and disturbed ecosystems, both spatial and temporal components need to be studied (Sousa 1984). Most ecological research is undertaken over historical timescales of less than 100 years (Schoomaker & Foster 1991, Harris & Thomas 1991). However, change and development within biotic systems is evident across a range of timescales, therefore ecological research is dependent upon the temporal scale employed (Foster *et al.* 1990, Armitage 1996). Hence, palaeoecology has the potential to provide solutions to the temporal problems and limitations relating to contemporary ecology (Singer *et al.* 1996). The utility of expanding the timescales of ecological research was shown by Jackson *et al.*'s (1988) analysis of hydroseral succession spanning a 3000 year period which showed that, apart from the arrival of initial pioneer species, vegetation communities at Miller Woods, near Lake Michigan, were unchanged until 150 BP. The recent change was attributed to human activity, rather than gradual autogenic succession over time. Through the analysis of long term ecological trends, Wells & Wheeler (1999) linked late Holocene vegetation development in a floodplain mire to climatic changes as opposed to vegetation succession. Similarly, Singer *et al.* (1996) used palaeoecological techniques to establish the relative influence of external and internal forcings on floodplain marsh vegetation succession over time. Despite the potential applications of the aforementioned

research, there remain few studies that have utilised palaeoecological methods to address ecological issues in floodplain contexts.

While palaeoecology may usefully inform ecological questions, the application of contemporary ecological data can also be essential for the interpretation of fossil data. In particular, information regarding the compositions of vegetation communities is instrumental in the assessment of anomalies in a fossil community (Gee & Giller 1991). Contemporary data, such as the recent series of National Vegetation Classification (NVC) in the UK, can be compared to fossil data, in order to identify species not usually found co-existing with others in the fossil community. Gee & Giller (1991) also discuss the application of indices, derived from modern empirical studies, for the analysis of temporal changes in biota such as diversity changes which can be linked to environmental conditions and disturbance.

Plant community research allows assessment of processes such as patch dynamics, and mechanisms including competition and life histories (Ritchie 1995), whereas fossil records only show patterns of change (Harris & Thomas 1991), for which causality is implied from analysis of species characteristics, and community composition change. A problem with palaeoecological approaches to ecological questions is the black box nature of interpretation. The input of other data sources, including sedimentological and geomorphological contexts (Collinson & Scott 1987), into investigations is thus recommended in order to analyse the processes and controls of vegetation change.

2.3.1 The palaeoecology of floodplain environments

Palaeoecological research has the potential to make significant contributions to our understanding of the archaeology and ecology of floodplain environments. For example, it has been observed over the past 10 years that in order to undertake comprehensive wetland restoration and rehabilitation, the temporal scale of floodplain research needs to be expanded (Amoros & van Urk 1989, Schropp 1995). This reflects the need to both conceptualise the former conditions of floodplain environments in order to restore contemporary habitats (Wheeler 1995), and to understand the dynamics of floodplain wetlands for the monitoring of restoration schemes (Henry & Amoros 1995). However, while comparatively few studies have been undertaken in this respect, recent progress has been made in furthering our understanding of changes in floodplain diversity. Brayshay & Dinnin (1999), for example, have used pollen and beetle data to reveal a significant decline in biodiversity during the Holocene along the River Trent floodplain. Ecological research in the Rhone catchment has

also attempted to expand the temporal scale of research but this work is still limited to historical timescales (e.g. Bornette 1991b, 1994a).

Despite the acknowledgement that floodplains have been the focus of human activity during the Holocene (Wiltshire & Edwards 1993, Passmore & Macklin 1997) and our need to understand the linkages between human activity and environmental change (Bell 1992, McCarthy 1995), much palaeoecological research has focused upon upland peatland and lacrustine environments due to a concern about the taphonomic problems relating to floodplain sediments (Scaife & Burrin 1992) and the difficulties in finding well preserved organic sediments. Indicators of micro- and macrofossil degradation and information regarding stratigraphic contexts of organic deposition have thus been applied within floodplain palaeoecological research (see Section 2.4.4) in order to address the issues of taphonomy (Brown 1997a, Scaife & Burrin 1992, Tipping 1995b, Moores 1998). Subsequently, biotic change observed in floodplain palaeoecological records has enabled the correlation of human activity and landscape development (Bell 1992). Wiltshire & Edwards (1993) and Brown (1997a), for example, found incidences of deforestation, dated to the late Neolithic to early Bronze Age transition and to 6000 BP respectively, from palaeoecological analyses of alluvial sediments while the rapid increase in human activity in North America following settlement was seen from significant increases in *Ambrosia* pollen in alluvial sediments (Baker *et al.* 1993). In upland British catchments, combined alluvial histories and palynological analyses have enabled correlation between landscape disturbance, increased fluvial activity and vegetation changes, such as deforestation and cultivation (e.g. Tipping 1992; 1998, Moores *et al.* 1999).

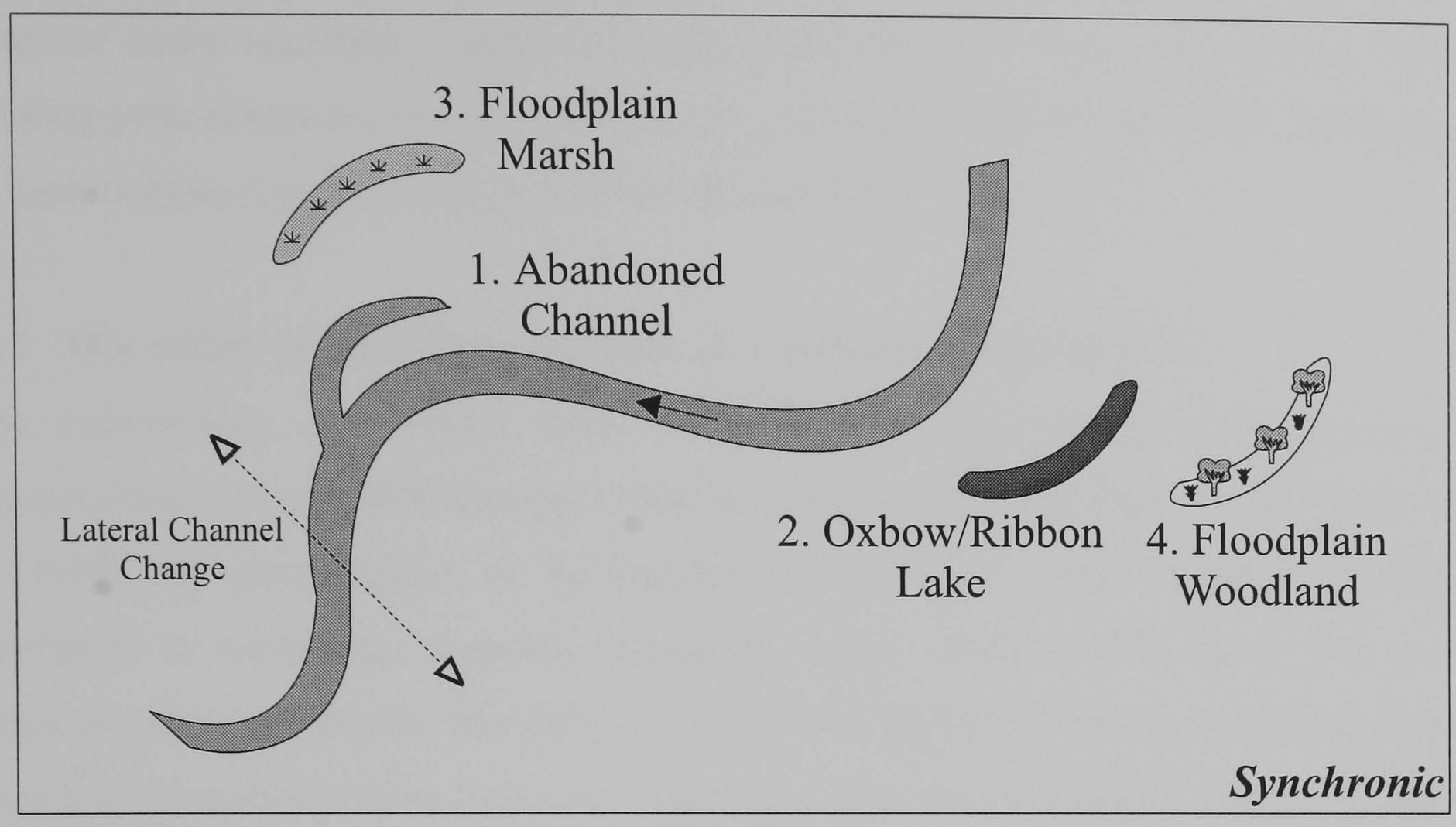
2.3.2 Spatial and temporal floodplain ecology analysis

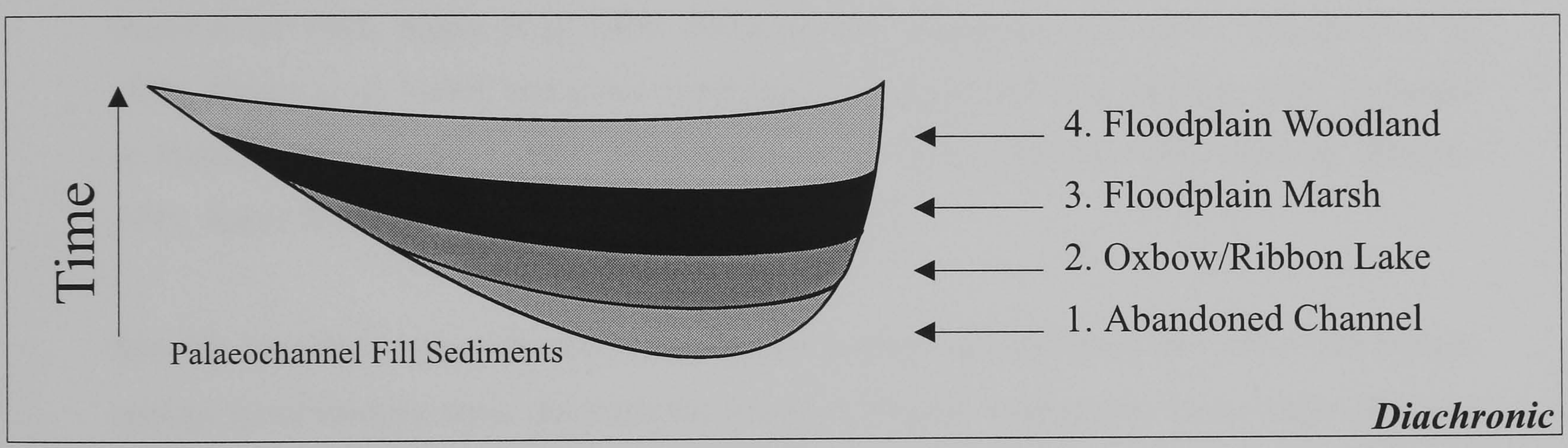
Due to the complex dynamics of floodplain systems incorporating the temporal scale, via palaeoecological analyses into research methodologies, whilst appreciating the spatial diversity of floodplain habitats has proved difficult in the past (Bravard *et al.* 1986). As a result Amoros *et al.* (1987) have developed a method of analysing ecological systems in fluvial environments which synthesises both temporal and spatial scales of ecological change. The method is based on the use of spatial (synchronic) data to interpret temporal (diachronic) changes in floodplain habitats. Primarily, Amoros *et al.* (1987) observed the succession of fluvial landforms created by lateral channel changes (section 2.2.2). These features, which form a chronology of palaeochannel forms, (e.g. side channels and oxbow lakes) which form ecological 'patches' (Pickett & White 1985, Johnson & Gage 1997) and have ecological, geomorphological and hydrological characteristics which define its stage of development. A

spatial succession of habitats therefore exists on the floodplain surface (Fig 2.1). The temporal succession of habitats exists within the palaeochannel fill stratigraphy, as the bottom of an alluvial channel fill represents the period following abandonment with subsequent infill sediments forming a chronological sequence of biotic development. Palaeoecological analysis of these sediments provides a reconstruction of the vegetation community development, the characteristics of which can thus be compared with spatially organised contemporary ecological data (Fig 2.1).

The technique was applied to a core taken from a palaeochannel in the Upper Rhône River by Amoros & van Urk (1989). Cladoceran remains were used as a palaeoecological tool to reconstruct the biotic characteristics of the habitat. The data showed a period of ecological succession, disrupted by increased water table heights at the beginning of the 20th century. The disruption caused a reversal or rejuvenation of the successional trend. Amoros & van Urk (1989) note that the utility of the technique is restricted to the palaeoecological approach applied. Pollen analysis of floodplain sediments for example provides data regarding the local, extra local and regional vegetation (Brown 1997a), the proportions of which are determined by the size of the water body into which the pollen grains are deposited (Jacobson & Bradshaw 1981). Such data therefore are problematic when attempting to reconstruct habitat scale vegetation change, as it has been calculated that extra-local and regional pollen can constitute up to a quarter of the pollen record in palaeochannels of 30m diameter with the proportion of long distance pollen increasing with the size of the receiving water body (Brown 1997a). Techniques recommended for the analysis of palaeochannel habitats include fossil insect analysis, diatom analysis and plant macrofossil analysis, all of which can produce habitat scale palaeoecological data (Amoros & van Urk 1989). Therefore, it has been identified that problems arise when linking palaeoecology and ecology due to the comparative scales of research. Neoecology, or contemporary ecology, has well defined spatial scales of vegetation analysis whereas palaeoecology has poorly defined spatial research scales due to ambiguities of fossil source areas (Ritchie 1995). Section 2.4 discusses the palaeoecological technique of plant macrofossil analysis which, with a more defined spatial scale of research than other techniques and a number of other advantages as discussed below, increases the potential for comparison with modern data (cf. Amoros & van Urk 1989).

Synchronic and Diachronic Organisation of Floodplain Habitats (adpated from Amoros *et al*, 1987)





2.4 Plant Macrofossil Analysis

Plant macrofossils are the visible remains of fruits, seeds, wood fragments, vascular plant fragments, bryophytes, and algae (Wasylikowa 1986) that may be deposited and preserved in sediments under anaerobic conditions. Lake sediments, peat bogs, and alluvial wetlands, including palaeochannels, provide the necessary environmental conditions for the deposition and preservation of plant material (Lowe & Walker 1997).

2.4.1 The utility of plant macrofossils as a palaeoecological tool

Plant macrofossils have been used as a tool for Quaternary palaeoenvironmental reconstruction since the 19th Century (Dickson 1970, Watts 1978, Birks, 1980). In the 1930s and 1940s the development of 'technically sophisticated pollen analysis' provided an opportunity to reconstruct regional vegetation change (Watts 1978) which thus reduced interest in plant macrofossils. However, in recent years there has been an increasing emphasis on the use of macrofossils in palaeoenvironmental reconstruction (Birks 1993). Macrofossils have thus been used to compliment and enhance multiproxy palaeoecological research (e.g. Ponel *et al.* 1992, Baker *et al.* 1993, Huntley 1993, Gajewski *et al.* 1995, Newnham *et al.* 1995, Tinner *et al.* 1996), and as a single palaeoecological tool (e.g. Jackson 1989, Wainman & Mathewes 1990, Birks 1993, 1994, Singer *et al.* 1996, Garneau 1997, Wells & Wheeler 1999, Baker 2000).

Specific benefits of macrofossils as a palaeoecological tool are discussed below and include species level identification, the potential for physiological assessment, *in situ* deposition and wide ranging vegetation community representation.

Species level identification

One of the main benefits of plant macrofossil analysis for palaeoenvironmental reconstruction is that well preserved macrofossils can be identified to species level. This yields more detailed ecological information than microfossils which are mainly identified to genus or family level (Watts 1978, Birks 1980, Mannion 1986a). Harris (1983) used this taxonomic accuracy to differentiate between wild and cultivated grass species when assessing the development of agriculture in North America, while species level identification of moss enabled Mauquoy & Barber (1999a) to reconstruct periods of climatic deterioration using the moisture sensitive species *Sphagnum imbricatum*. In distinguishing between *Betula papyrifera* (representing dry conditions) and *Betula lutea* (indicative of wet conditions) Swain (1978) was able to reconstruct environmental change over the past 2000 years from lake sediments in Wisconsin, USA. Taxonomic accuracy was also required by Allen &

Huntley (1999) for research into temporal and spatial variations in montane biodiversity and by a number of studies investigating treeline fluctuations over the Holocene as proxy climate records (e.g. Jackson 1989, Tinner *et al.* 1996, Fall 1997).

Physiological analysis

Analysis of macrofossil remains at high magnifications can provide detailed information regarding the species physiological characteristics. For example, from physiological analyses of Hemlock macrofossils, Filion & Quinty (1993) identified the cause of Hemlock decline in the fossil record of the north west United States around 5000BP. They found no evidence of fungus or pathogens, but were able to detect water damage to the species and hence attributed the decline to climatic deterioration. Due to the difficulties in distinguishing grass pollen in African lake sediments Palmer (1976) used the anatomical characteristics of macrofossil remains to identify grass to genus level. In the past ten years there has been an increase in the use of stomata on leaf remains as a record of atmospheric CO_2 levels. Research on different tree species has revealed an inverse relationship between the density of stomata and CO_2 levels in the atmosphere (Beerling 1999). Stomata analysis has been successfully applied by Beerling *et al.* (1995) to record CO_2 levels indicated by stomatal density on *Salix herbacea* leaves dating to the late Glacial early Holocene transition. Morphologically distinctive stomata on *Thuja* and *Juniperus* species have also been used to identify their remains from Crawford Lake, Ontario (Yu 1997).

Deposition in situ

Plant macrofossils are thought to represent the local vegetation of a site (Watts 1978, Birks 1980) due to the size of plant remains and the nature of deposition (Wasylikova 1986). Generally, seeds and fruits are not dispersed more than 200m from their parent plant (Field 1992). To test this theory, a number of studies have compared sub-fossil species assemblages with the composition of the surrounding vegetation (e.g. Drake & Burrows 1980, Collinson 1983, Greatrex 1983, Dunwiddie, 1987, Burnham *et al.* 1992). One of the first thorough investigations of this kind was undertaken by Birks (1973). Her study was done on lake sediments in Minnesota where sharp boundaries exist between the major vegetation associations in the region. The results showed the species assemblages in the surface sediments to represent both the aquatic and wetland vegetation of the lake, as well as the surrounding and upland or prairie vegetation communities, all of which could be distinguished in the fossil record.

In situ deposition of plant macrofossils has been applied in the assessment of vegetation migration rates and timing. Birks (1993) surmised that the lack of *Betula* macrofossils in Norwegian lake sediments indicated the *Betula* pollen present in the same sediment was of extra regional origin. The findings had a significant influence on the calculations of mean annual temperatures in Scandinavia during the Allerød period. Jackson (1989) used macrofossils to assess the earliest dates of arboreal presence in the north east United States, in order to avoid problems associated with long distance wind blown pollen grains in the fossil record. Finally, the localised deposition of plant macrofossils provides a scale at which fossil and contemporary communities can be compared, as data within a macrofossil record is analogous with that from contemporary vegetation communities (Wells & Wheeler 1999, Baker 2000).

Representation of wetland species

The presence of aquatic species in the macrofossil record is important in palaeoenvironmental reconstruction as, being pioneer species, aquatics respond rapidly to environmental change (Watts 1978). Vegetation responds to a variety of environmental change parameters including climate, growing season, water table height, nutrient status (Watts 1978, Birks 2000) and water conductivity (Birks 1973). Many aquatic and wetland species, however, are not well represented in the pollen record (Birks 1980). Analysis of seed production rates for aquatic species has revealed that some species can produce over two million in one flowering season (Yeo 1966). Furthermore, macrofossil studies have shown the excellent preservation of wetland and aquatic species, such as *Selaginella selagniodes* and *Najas minor*, in sediments dating back to the early Pleistocene (Gibbard *et al.* 1996).

Preservation potential

Another benefit of plant macrofossils as a tool for palaeoenvironmental reconstruction relates to their tolerance of minor changes in watertable levels (Brown 1997a). Complete aerobic conditions can only be tolerated by charred remains (Hillman 1981), however, occasional drying such as that experienced on a seasonal basis in lake and floodplain environments does not severely affect the preservation potential of macrofossil remains.

In summary, the *in situ* deposition of plant macrofossils enables reconstruction of local vegetation communities, the characteristics of which can be ascertained from the potential species level identification of remains. With specific reference to floodplain habitats, wetland and aquatic species are well represented within the macrofossil record while tolerance to

minor water table fluctuations could also be beneficial in the palaeoecological analysis of wetlands and mires.

2.4.2 Palaeoenvironmental reconstruction: 1. The Quaternary to recent historic

The utility of plant macrofossils for Quaternary and Holocene environmental reconstruction has been demonstrated in a number of studies over the past four decades. The approach was used to evaluate variations in the early Pleistocene interglacial climate (Gibbard *et al.* 1996), to reconstruct temperate deciduous woodland from the Hoxnian interglacial (Boreham *et al.* 1999) and estimate the percentage of species exotic to Britain that were present in the early Quaternary stages (Wilson 1983). Furthermore, macrofossil analysis by Mitchell (1951) and Watts (1967) has enabled comparison of vegetation communities and climate conditions between Britain and Ireland during the Quaternary. Other studies undertaken on Quaternary sediments have assessed changes in species distribution patterns (Godwin 1957), occurrence (Birks 1980) and ecological tolerances (Watts 1978) in comparison with contemporary ecological data. Most of the above studies were undertaken on lacustrine deposits with few examples of macrofossil analysis of alluvial sediment. A rare study was undertaken by Field (1993) who extracted macrofossils from Pleistocene channel fill sediments to reconstruct the local vegetation and determine possible evidence of an additional temperate warm stage between the Hoxnian and Ipswichian interglacials in Buckinghamshire.

Plant macrofossils have frequently been used to evaluate the rate of climatic and associated vegetation change occurring at the end of the Devensian glaciation (e.g. Beerling *et al.* 1995, Birks 1993, 1994, Hickman & Schweger 1993, Jackson 1989, van Geel *et al.* 1989, Watts 1967). Macrofossil research over Holocene timescales has included the analysis of vegetation development (Tallis and Switsur 1983, Levesque *et al.* 1994), the hemlock decline in north east USA (Filion and Quinty 1993), and changes in tree line altitude (Tinner *et al.* 1996, Van Dinter & Birks 1996). Baker *et al.* (1994) found arboreal pollen too dominant in the fossil pollen record to allow an assessment of prairie development during the mid-Holocene, but using macrofossils were able to determine the presence of prairie species from 4800 BP to 2900 BP.

The use of plant macrofossils in archaeological studies has resulted in the development of the sub-discipline 'archaeobotany' which concentrates on the analysis of the relationship between humans and plants (Figueiral & Willcox 1999). Macrofossils used in archaeobotanical research include both waterlogged remains, those preserved under anaerobic conditions, and charred remains. The latter are most commonly used as they are

preserved under aerobic (dry) conditions (Huntley 1997). The majority of archaeological studies using macrofossils concentrate on the development of prehistoric and historic agricultural practices. From charred remains information can be derived about a variety of agricultural processes including threshing, reaping, and tilling methods (Hillman 1981). Due to the widespread use of wheat (*Triticum spp*) across Europe, assessments of regional differences in the fossil record can reveal the changing nature of agriculture at different spatial and temporal scales (Hillman *et al.* 1995). Archaeobotanical studies have also evaluated pre-agricultural practices such as the exploitation of wild species (Harris 1983).

2.4.3 Palaeoenvironmental reconstruction: 2. Lake, peat, mire and fluvial environments.

It is been suggested that small lakes and ponds with neither major inflows nor outflows are the most ideal environments for macrofossil analysis due to the negligible inputs of allochthonous (*ex situ*) material which potentially contaminate the fossil record (Watts 1978). Past analyses of macrofossils from lake sediments have been done to assess the nature of vegetation development in response to climate change in lakes throughout the Holocene (e.g. Van Geel *et al.* 1989, Jackson 1989, Birks 2000) and as a proxy climate indicator (e.g. Yu & Andrews 1994, Vance *et al.* 1997, Magny & Richoz 1998). The technique is based upon identifying zones of aquatic and wetland vegetation in lake sediment sequences whose ecological tolerances depict the water level contemporary with deposition (Hannon & Gaillard 1997). As ecological tolerances relate to water chemistry change, such as eutrophication, as well as hydrological change, the importance of using trends based on a combination of species' niche data as opposed to individual species data, to interpret a fossil record has been emphasised (Hannon & Gaillard 1997). For example, Birks *et al.* (1976), combined information regarding species' habitat niches when assessing the eutrophication of a lake from a macrofossil record. The data provided an overview of ecological change and subsequently enabled the effects of eutrophication to be disseminated from variations in lake level. The development of vegetation communities in a lake catchment has also been analysed using plant macrofossils. Holocene variations in arboreal species around Marion Lake, Canada were reconstructed by Wainman & Mathewes (1987) while Yu (1997) evaluated change in *Thuja* and *Juniperus* populations around Crawford Lake, Canada.

Research on ombrotrophic peat bogs and fen peat has used macrofossils despite difficulties in their extraction from fibrous sediments (Birks 1980). Macrofossils in peat environments can define the trophic status of a bog (Grosse-Braukemann 1986) and, although seeds and fruits

are well preserved in peaty sediments, mosses are more commonly used in macrofossil research from these environments (Dickson 1986). Barber (1981) used macrofossils, specifically the *Sphagna,* to evaluate the processes of ombrotrophic bog regeneration. His findings demonstrated climatic forcings to be an over-riding control on peat development, thus emphasising their utility as proxy climate indicators. Subsequent studies, using *Sphagnum* from ombrotrophic bogs, have enabled the reconstruction of high resolution climatic variations throughout the Holocene (Haslam 1987, Barber *et al.* 1994b, Mauquoy & Barber 1999a; 1999b).

Despite the techniques being widely applied in lake and bog environments, few studies have used floodplain environments for macrofossil studies. Floodplain mire environments have, however, provided material for macrofossil analyses. Wells & Wheeler (1999) extracted macrofossils from a core taken from a floodplain mire in the Norfolk Broads, UK which spanned the past 2000 years. This enabled the researchers to assess the changing influence of human intervention on the floodplain over this time period. Only in the past 400 years had human activity severely affected vegetation at this site. Singer *et al.*'s (1996) comparisons of upland and floodplain mire vegetation changes has, by contrast indicated hydrological change resulting from climatic fluctuations as a major forcing in vegetation development.

In general, macrofossils in floodplain environments tend to be best preserved in former river channels and oxbow lakes (Birks 1980) and although comparatively few studies have been undertaken in fluvial environments, such research can provide important information regarding the implications of hydrological change and human activity on floodplain vegetation. For example, the varying influence of the fluvial system upon floodplain vegetation along the Goulais River, Canada, was observed by Warner *et al.* (1987) who were able to reconstruct vegetation change from communities which reflected a dynamic hydrological regime to those indicative of calmer open water sedge communities. Baker *et al.* (1993) also observed a shift in the composition of floodplain vegetation communities over the past 200 years resulting from increases in human activity in the catchment. Here, macrofossil analyses revealed a reduction in natural vegetation communities and large increases in ruderal species, corresponding to deforestation and increases in cultivation on the valley floor. One reason for the low numbers of macrofossil studies on floodplain sites is the absence of well preserved organic sediments (cf. Tipping 1995a). Secondly, there also persists concern regarding the taphonomy of macrofossils in alluvial sediments due to the possibility of long distance transport prior to deposition and reworking of material (Amoros *et al.* 1987, Brown 1997a). The issue of taphonomy is discussed in greater detail below.

2.4.4 Taphonomy

Taphonomy may be defined as the processes which influence plant representation in sediments (Collinson & Scott 1987), and dictates the extent to which a fossil community represents the original vegetation composition. A potential macrofossil has to survive a number of processes between initial creation and deposition and the final composition of the fossil community (Fig 2.2). Considerably more attention has been paid to pollen taphonomy (e.g. Traverse 1990, Scaife & Burrin 1992, Smirnov *et al.* 1996) compared to macrofossils (Birks 1973, Field 1992). Despite the potential for using macrofossils in Holocene and Quaternary research, there remain few studies on the taphonomic issues of macrofossil analysis. Field (1992) lists the main influences on the composition of the macrofossil record which include:

1. Seed productivity
2. Dispersal and reworking
3. Dormancy and germination
4. Predation and preservation

1. Production

The primary influence on the correlation between a fossil and the original vegetation community is the seed production rate of individual species. Yeo (1966) proved that the difference in seed production rates in aquatic species was in the order of thousands of magnitudes. This variability in production relates to the weight of the plant, the energy attributed to seed production, and the number of seeds produced per unit weight (Harper *et al.* 1970). Harper *et al.* (1970) also observed the importance of seral stage on seed production. Pioneering species have a tendency to produce large numbers of seeds whereas stable, late successional species have lower production rates. Subsequently, macrofossil data can be skewed towards those species with high production rates (Watts 1967). Such information must therefore be incorporated into the interpretation of macrofossil data. Vegetative reproduction can also create bias in the macrofossil record. Watts (1978) notes that during periods of ecosystem stability certain species may preferentially reproduce vegetatively as a result of increased competition. Abernethy & Willby (1999) observed greater numbers of seed and species diversity within a seed bank in disturbed alluvial wetlands than the less frequently flooded backwater wetlands. Seed production variability therefore exists both between and within species, and species that reproduce vegetatively could be under-represented in the macrofossil record (Wasylikova 1986).

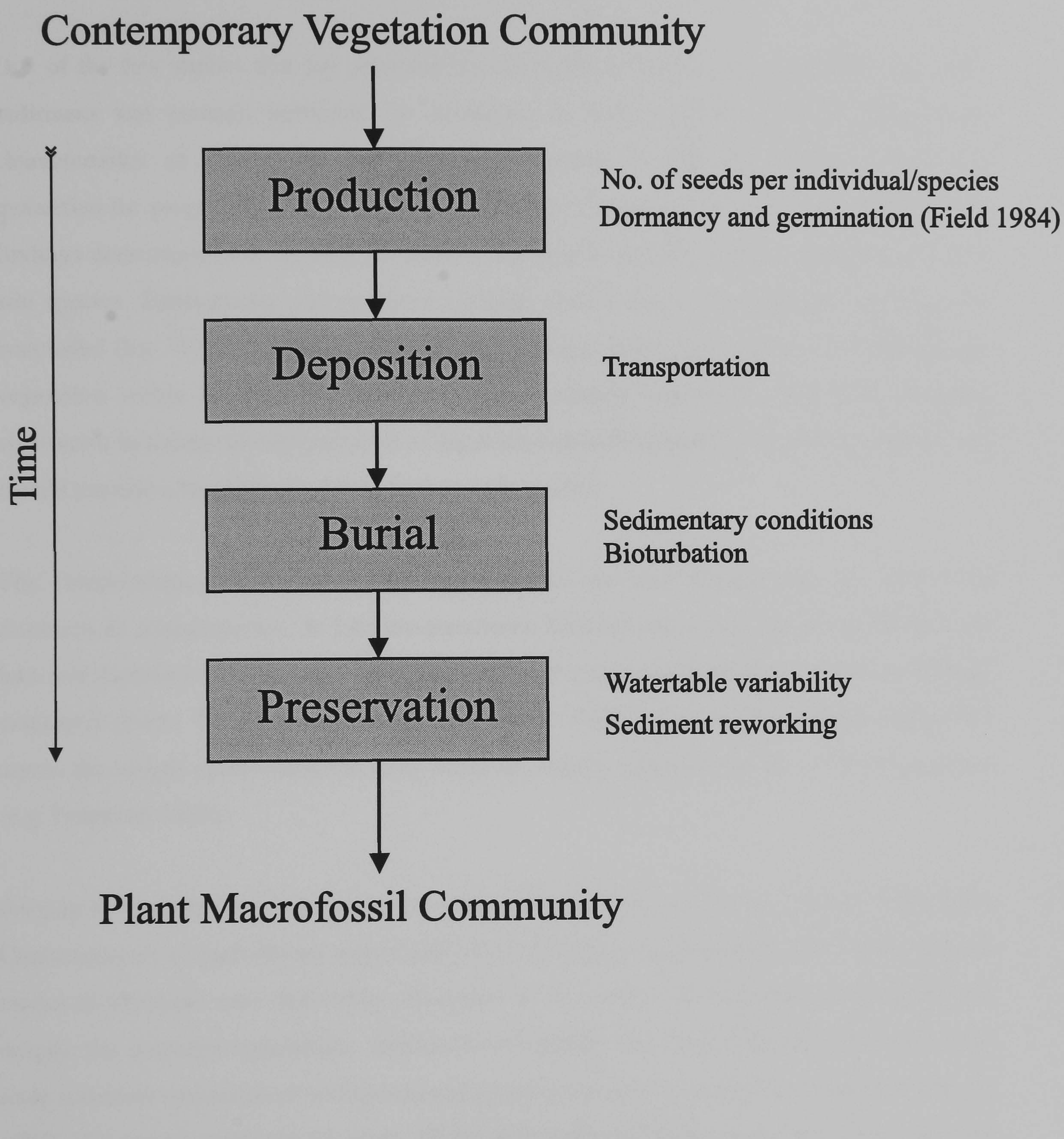
2. Dispersal and reworking

One of the main advantages of macrofossil analysis for palaeoenvironmental reconstruction is the mode of deposition as burial of seeds *in situ* results in the creation of a macrofossil record representative of vegetation in the immediate locality. However, there are other media by which macrofossils can reach their final point of burial. Alexander *et al.* (1999) listed some other mechanisms of plant deposition; burial having fallen onto a feature, burial following wind transportation, transport *via* water then burial and the re-working and subsequent re-burial of subfossils. Remains which have fallen directly onto a feature, and incorporated into the sediment are representative of *in situ* vegetation if not subsequently transported. Direct fall was considered (along with stream transport) as one of the most important mechanisms of dispersal by Drake & Burrows (1980). Dunwiddie (1987) evaluated the importance of direct fall by analysing the composition of conifer needles in surface sediments beneath a conifer association. Results showed the proportion of needles per species to be correlated with the proportion of the forest floor area occupied by each species. While turbulent wind can bring about the long distance transport of plant macrofossils (Watts 1978) such meteorological conditions in temperate environments do not tend to significantly affect the macrofossil record (Birks 1980). Species whose seeds exhibit adaptations for wind transport, such as *Betula spp* and the Asteraceae and Poaceae families, can be transported short distances prior to deposition. The main potential modes of long distance dispersal therefore are water transport in a variety of forms and the reworking of previously deposited remains.

Much of the work on the dispersal of plant remains has concentrated on lacustrine environments. Birks (1973) established a methodological approach to the assessment of macrofossil dispersal in her study of surface lake sediments in Minnesota. Her research revealed that while the macrofossil record was dominated by aquatic and wetland species, it also contained remains from the vegetation communities immediately surrounding each lake. The dominant mode of deposition therefore was *in situ*, although *ex situ* remains were also only derived from local sources, therefore showing little evidence of long distance transport. From work on lake sediments in southern England, Collinson (1983) found that the macrofossil composition in surface samples related to the distance of the sampling point to the stream inflow to a lake. Further away from the inflow, the macrofossils were dominated by *in situ* vegetation whereas closer to the inflow, species from the stream catchment were present. The influence of stream flow was acknowledged by Drake and Burrows (1980) who also noted the sedge or fen vegetation around the edge of a lake acted as a filter to potential

Figure 2.2

Diagrammatic Representation of Plant Macrofossil Taphonomy



macrofossils. This filter effect reduced the number of terrestrial macrofossils reaching lake surface sediments. Greatex (1983) also documents the filter effect from taphonomic studies in fen and swamp environments and argues that unless species exhibited specific transport adaptations they would travel less than one metre before burial.

One of the few studies that has assessed the character of species representation in riverine sediments was recently published by Abernethy & Willby (1999), who investigated the characteristics of seed banks and propagule dispersal in alluvial wetland habitats and quantified the proportions of *ex situ* and *in situ* species represented in surface samples. Their findings determined that 73-78% of seeds in frequently flooded habitats originated from *in situ* species. Furthermore, the summary findings from a series of floodplain wetland sites concluded that 75-95% of the seeds in alluvial settings derive from either the contemporary vegetation within the habitat or the proximal floodplain vegetation. This work is highly significant in aiding the interpretation of plant macrofossil taphonomy in alluvial settings and should provide a template for future taphonomic studies.

The characteristics of potential plant macrofossils can also dictate possible modes and distances of transportation. In lake environments, buoyant seeds may travel further into the lake and therefore their inclusion in a sediment core is dependent upon the sampling strategy employed (Birks 1973, Hannon & Gaillard 1997). Taphonomic studies which specifically assess the weight of macrofossils have, however, mostly related to studies of leaf fragments (e.g. Ferguson 1985).

Proving long distance transportation from the macrofossil record can be difficult (Hill 1981). Characteristics of macrofossil deposition within floodplain stratigraphy which infer specific modes of transport were derived by Alexander *et al.* (1999). The techniques they employed, despite the potential taphonomic information available (see *Dispersal* above) require large scale sediment extraction or well preserved cut bank sections. From their observations on the effect of bedload transport on seeds, Huber & Ferguson (1998) considered well preserved macrofossils as indicative of low energy transportation, whereas increases in flow rates resulted in the degradation of macrofossils and reduced the possibility of identification. Degradation as an indication of long distance transport has also been suggested by Brown (1997a) and is a technique that has been successfully applied in the analysis of pollen taphonomy in floodplain environments (Tipping 1995b, Moores 1998).

Additional problems for macrofossil interpretation due to dispersal mechanisms have been seen from the analysis of deltaic sediments. Investigations of macrofossils within river delta sediments by Spicer (1981), found evidence for sorting whereby locally derived macrofossils were more abundant lower in the stratigraphic column by comparison with those which had travelled longer distances. The observation of such trends, however, are dependent on sediment accumulation rates. The dynamic nature of deltaic environments also results in a mixture of potential transportation modes. As a result of such complications, Warner & Barnet (1986) recommended the analysis of the stratigraphy and sediments from which the macrofossils are extracted to provide an indication of the hydrological conditions during deposition and hence the probability of whether remains derive from allochthonous or autochthonous sources.

The implications of reworking of sedimentary contexts in which macrofossils are preserved has received little attention within taphonomic research. Warner & Barnet (1986), in their analysis of pro-glacial lacrustine and deltaic sediments, account for the reworking of sediments and concluded that sedimentary analysis was required in order to understand the conditions of macrofossil deposition. The problem of reworked sediments can be linked to studies of sediment transport and provenance within both lake and river catchments, which is dependent upon numerous environmental factors (Passmore *et al.* 1994). Investigations into the possibility of reworked macrofossils therefore must concentrate on the reconstruction of geomorphological and hydrological conditions at a site.

3. Dormancy and germination

The extent to which dormancy and germination affect the creation of a macrofossil record is determined by the reproduction strategies of a species. Dormancy occurs when environmental conditions are not preferable for species germination (Harper *et al.* 1970) and certain species use dormancy as a tactic for surviving periodic environmental hazards *via* the deposition of a seed bank (Abernethy & Wilby 1999). The presence of a seed bank will result in abnormally high seed counts at the level of deposition. Research into the transport of seeds in fluvial environments has been undertaken in the context of contemporary regeneration and colonisation of aquatic environments (e.g. Barrat-Segretain 1996, Cellot *et al.* 1998, Barrat-Segretain & Bornette 2000). The research has demonstrated the importance of overbank and backwater flows in seed transport, which enable propagules to enter cut-offs and establish if areas are available, and suitable, for generation (Amoros & Bornette 1999). Primarily, therefore, assessment of the nature of sedimentation is required to determine the probability

of a seed being brought into the habitat via water transport. Secondly, analysis of the patterns of species presence is necessary to determine the probability of a seed being part of the fossil record due to conditions not suitable for its germination, or due to seed production from species established within the palaeochannel.

4. Predation and preservation

Large numbers of seeds produced are thought to be consumed by animals and fungi (Watts 1978). In some cases, potential macrofossils can pass through digestive systems and still be incorporated in the fossil record, as is the case for example with pondweed seeds consumed by ducks (Martin 1951), while Field (1992) noted that predation by birds can result in the long distance transport of macrofossils, especially during migration season. Alternatively, some species produce seeds adapted to deter predation, with features such as spines, bristles and hooks.

One major advantage of plant macrofossil analysis over pollen analysis in reconstructing vegetation change over time is their survival in sediments subject to water table variation (Dickson 1970, Brown 1997a). Nevertheless, macrofossils can degrade over time if subjected to specific environmental conditions, and according to the morphology of each seed (Cappers 1993). As a result of variations in biodegradation of seeds, perishable plant remains can be under-represented in the fossil record (Holyoak 1984). For example, the presence of predominantly durable seeds in lake sediments was interpreted by Collinson (1983) as resulting from poor preservation conditions over time. Conditions of deposition have also been found to influence macrofossil preservation. From the sampling of surface sediments, Field (1993) noted only low numbers of macrofossils were preserved on river point bars. The hydrological conditions during burial can also affect seeds due to differences in water absorption and desiccation, according to the surface morphology and area of each species (Harper *et al.* 1970).

In summary, plant macrofossils have the potential to reconstruct *in situ* aquatic and wetland vegetation communities at habitat scale. Although numerous studies have reconstructed environmental change in a variety of contexts using plant macrofossils, few studies have used macrofossils as a palaeoecological tool in alluvial environments due to the problems of finding organic rich sediments and problems of taphonomy. However, issues of *ex situ* plant macrofossils can be evaluated through determination of the context of deposition while an

understanding of species ecology can be used to evaluate bias in the fossil record caused by seed banks, variability in seed production and preferential preservation.

Chapter Three

Site Description

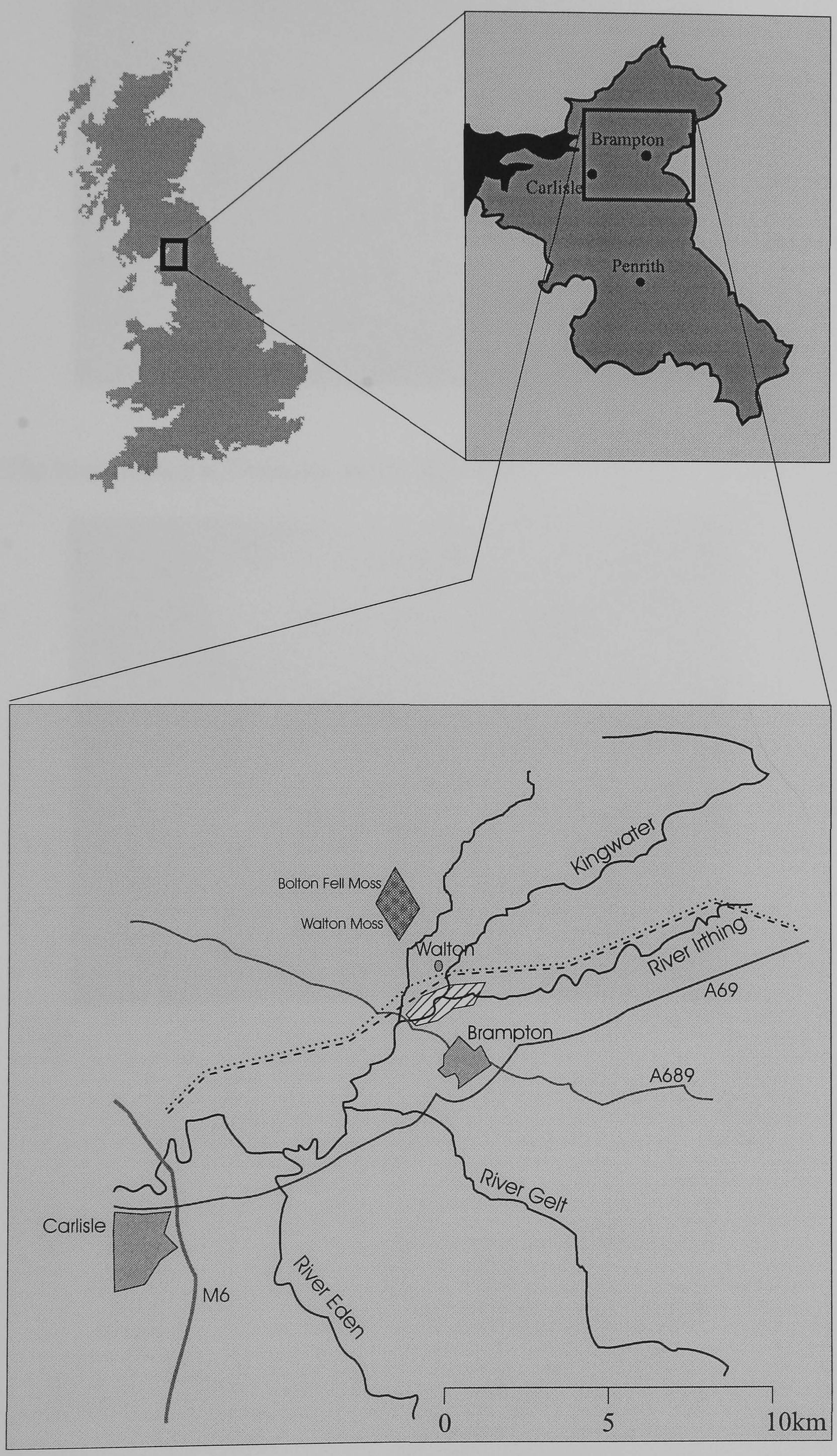
Chapter 3 firstly explains the methods and rationale of the research site selection. A description of the River Irthing catchment, and the sites selected for detailed research is provided in Section 3.1. The magnitude and characteristics of regional, prehistoric and historic human activity are discussed in Section 3.2 and are followed by an explanation of the proxy climatic records for the area and documentary records for environmental change in Section 3.3.

The River Irthing (Plate 3.1a & 3.1b) is a tributary of the River Eden, the confluence of the two lying 8 km to the east of Carlisle (Fig 3.1). The total length of the river is 61 km, with its catchment covering much of northern Cumbria including a section of Kielder Forest and associated peatlands. The underlying geology of the catchment is diverse (Fig 3.4). Interbedded folded Carboniferous limestones underlie the headwaters to the east of Lanercost (NY552633). To the west are Triassic sandstones which underlie the middle and lower valley reaches. The upper reaches of the catchment are incised into till resulting in steep valley slopes, rapid response to rainfall events and providing a high potential sediment yield. In the middle reaches the valley floor width is variable due to the local presence of glacial sands, gravels and till along the valley sides (Fig 3.4).

The Tyne-Solway corridor, the area linking Newcastle in the east to Carlisle in the west of northern England has been recognised as an important region with respect to its environmental history. Recently such acknowledgement has instigated a programme of research to investigate Holocene changes in both natural and anthropogenic landscape (Tolan-Smith 1997). The River Irthing catchment, northern Cumbria for example, has received little attention with respect to Holocene valley floor development. Preliminary investigations, however, have revealed the presence of well defined fluvial terraces along the middle reaches of the river, with organic sediments preserved within palaeochannel fills (Cotton *et al.* 1999). The significance of the site derives from its proximity to a number of ombrotrophic bogs from where proxy climate records, alongside palynological records, have been obtained (Barber *et al.* 1993, 1994a, 1994b, Dumayne & Barber 1994, Mauquoy & Barber 1999a). Furthermore, the valley sides of the River Irthing are followed by the route of Hadrian's Wall, which crosses the river at Birdoswald Fort (Fig 3.1).

Figure 3.1

Study Reach Location



Extended study reach

Urban areas

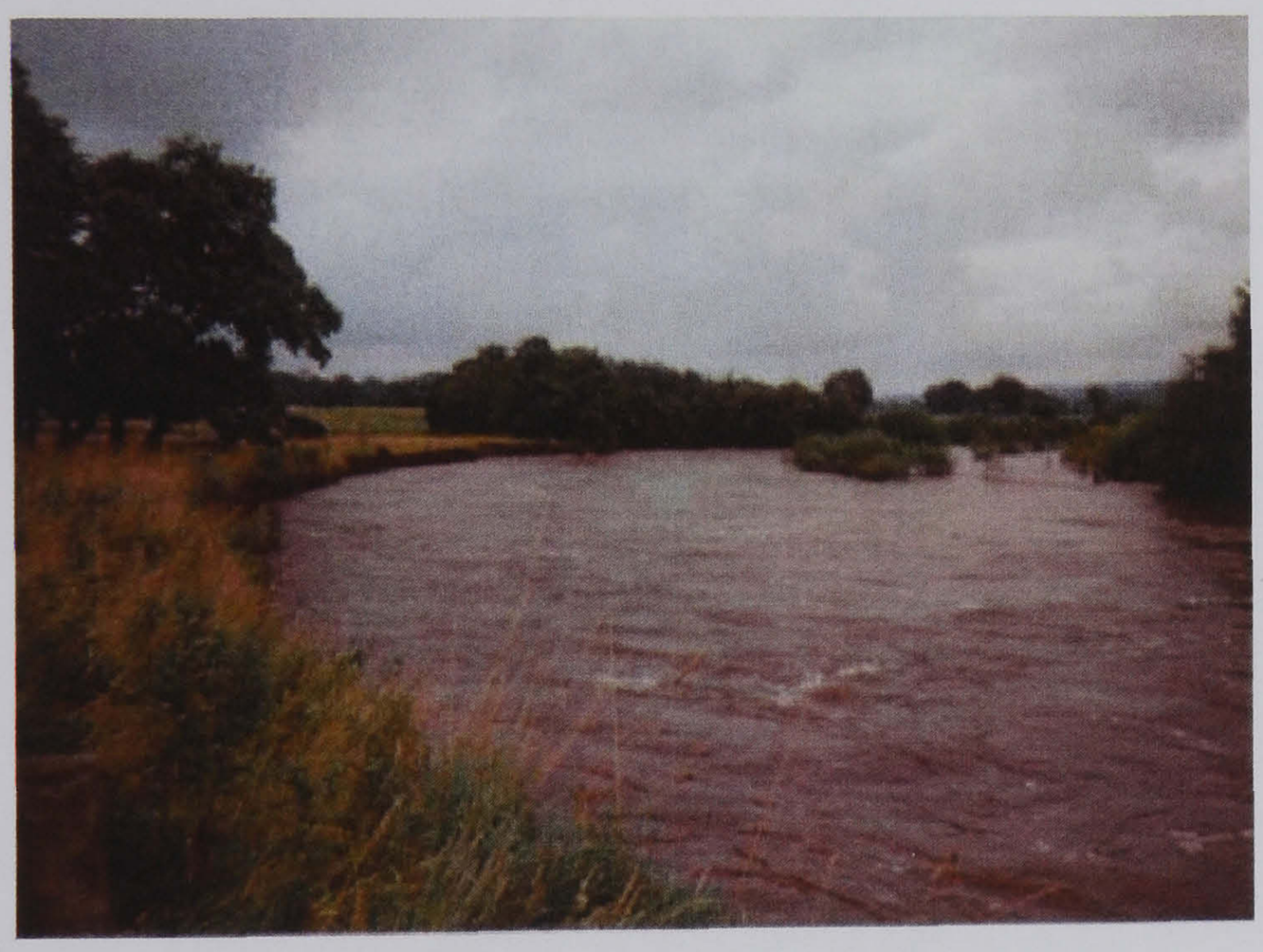
River Eden catchment

..... Route of Hadrian's Wall

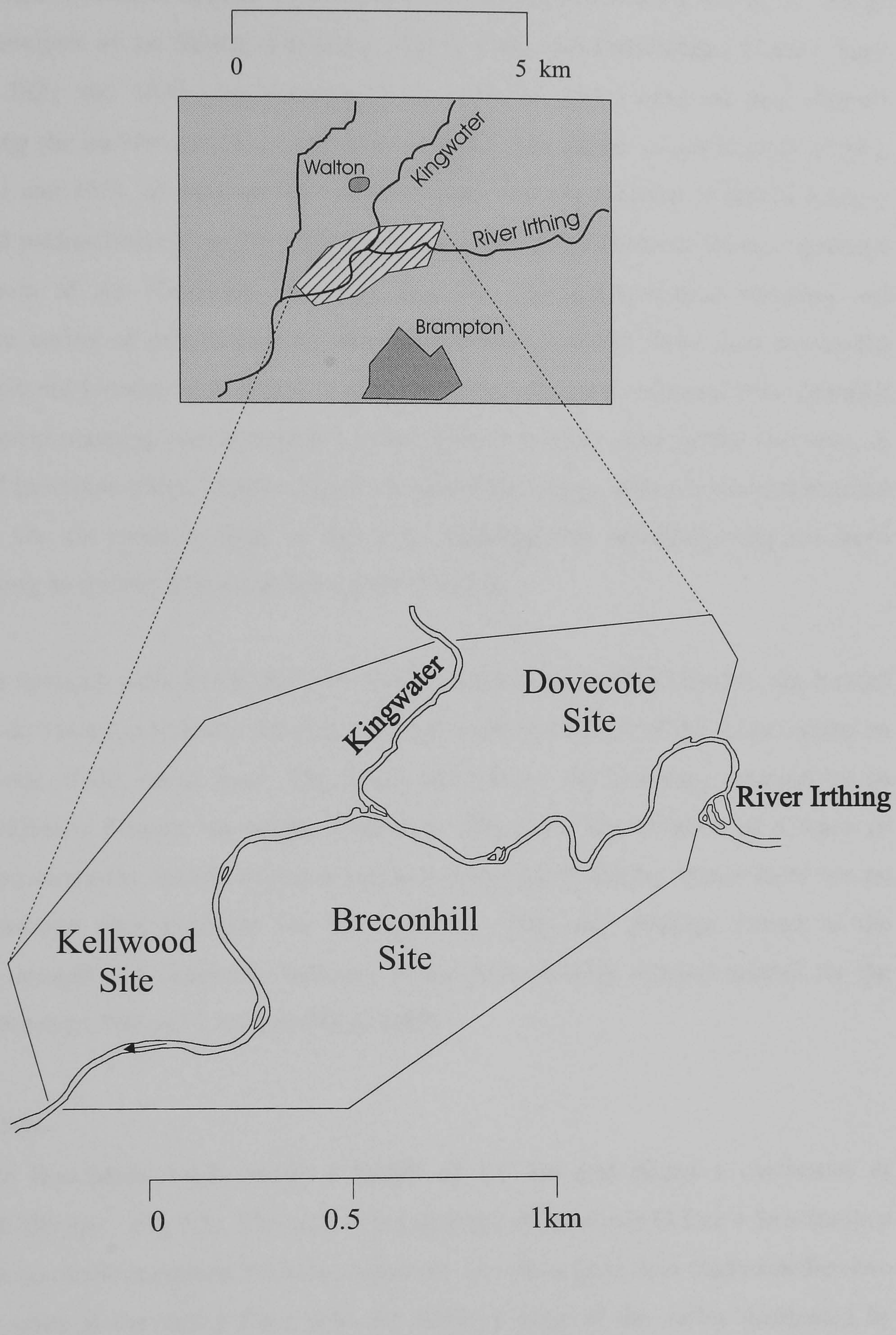
- - - - - - - - Route of Vallum

Plate 3.1a The River Irthing at Dovecote during low flow

Plate 3.1b The River Irthing at Dovecote during high flow



Extended Study Reach Location



3.1 The Study Reach

In order to locate a suitable section of floodplain for investigation along the River Irthing valley floor, analysis of 1st Edition Ordnance Survey maps and Cumberland County maps (dated 1771, 1821 and 1840) was undertaken, in order to locate areas of past channel instability along the middle reaches of the River Irthing. Assessment of aerial photographs, dating to 1951 and 1971, of selected reaches established the preservation of fluvial terraces and associated palaeochannels on the valley floor along an extended reach, located upstream and downstream of the Kingwater tributary (Fig 3.3). Geomorphological mapping and reconnaissance coring of palaeochannels along this reach identified three sites possessing well defined fluvial terraces and organic sediments within the palaeochannel fills. Detailed geomorphological mapping and surveying was undertaken on three sites, whilst two sites, at Kellwood and Dovecote Farm, lying on the north side of the valley were selected for detailed investigation. On the southern bank of the river, mapping and surveying only has been undertaken along an extended reach at Breconhill (Fig 3.3).

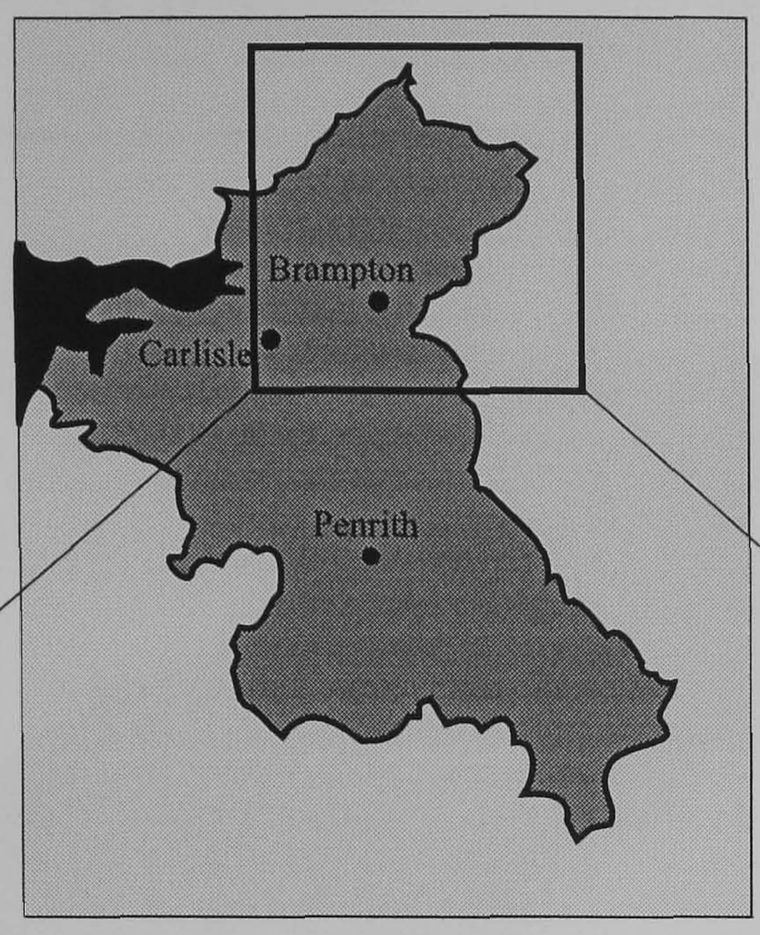
The two main research sites, Dovecote (NY530635) and Kellwood (NY518630), are located upstream and downstream respectively of Kingwater, a major tributary of the River Irthing on the northern side of the valley floor. The Kingwater follows the boundary between the St Bees and Kirklinton Triassic sandstone formations (Fig 3.4). The absence of a stage or gauging station along the middle to lower reaches of the River Irthing means there are no published discharge data available for the two sites. The only gauging station in the catchment is situated in a headwater tributary of the River Irthing. Annual rainfall for the catchment is between 900 and 1100mm (NRA 1995).

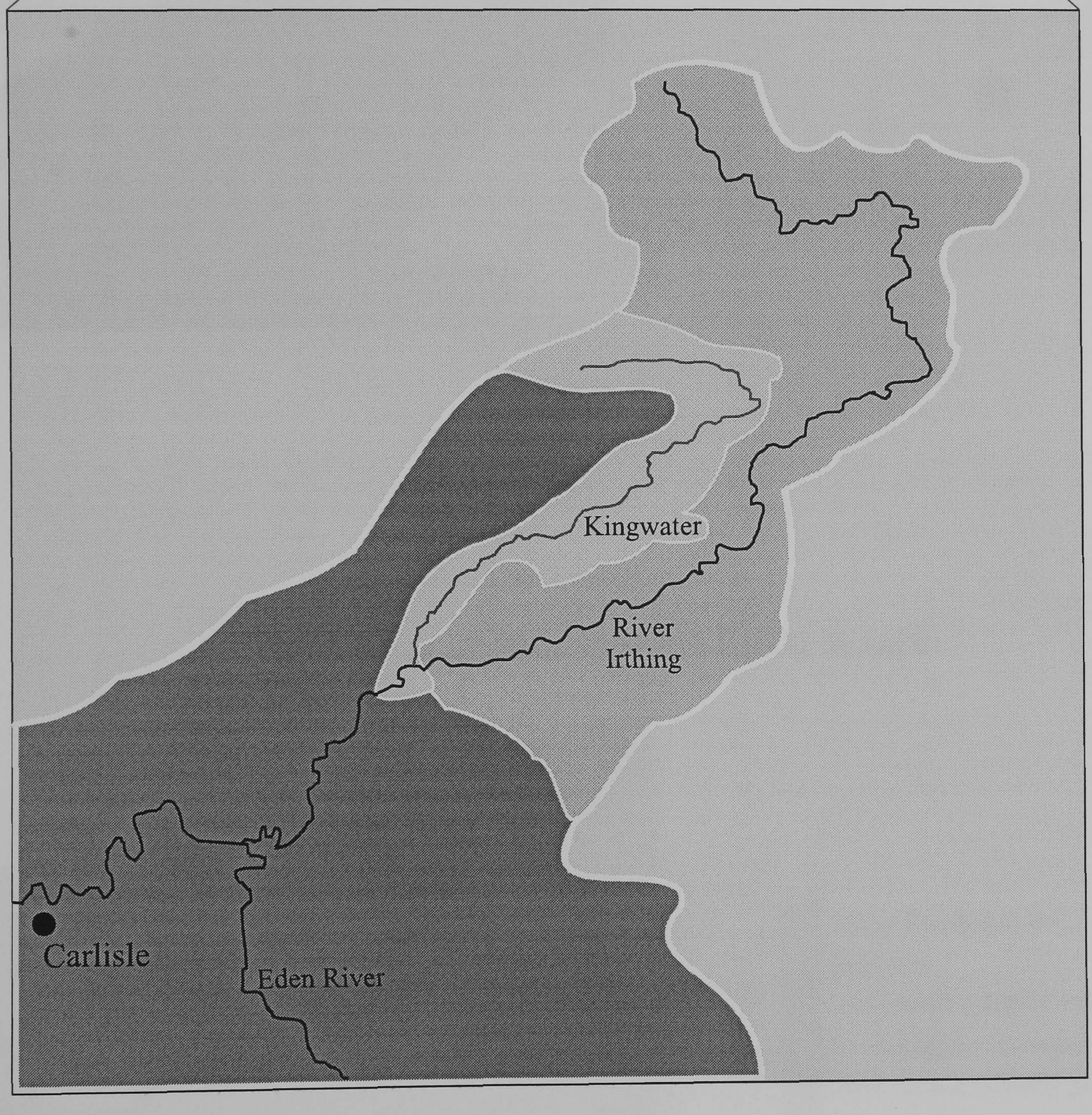
3.1.1 Dovecote

The Dovecote floodplain reach covers a length of 1.2 km and drains a catchment of approximately 170 km^2 (Fig 3.2). The underlying geology of the site is St Bee's Sandstone; a red/brown fine to medium grained Triassic sandstone. The geological drift map identifies two major terrace units at the valley floor with the northern edge of the valley delineated by Pleistocene sands and gravels (Fig 3.4). The valley floor is 700-800m across, with the present channel confined to the southern side of the floodplain. Below the steep valley sides at the Dovecote reach a series of step-like fluvial terraces are preserved with associated sinuous palaeochannel forms, many containing organic fill sediments. A former flood basin is located

Catchment Map For the River Eden, River Irthing and Kingwater

Figure 3.3





Eden Catchment

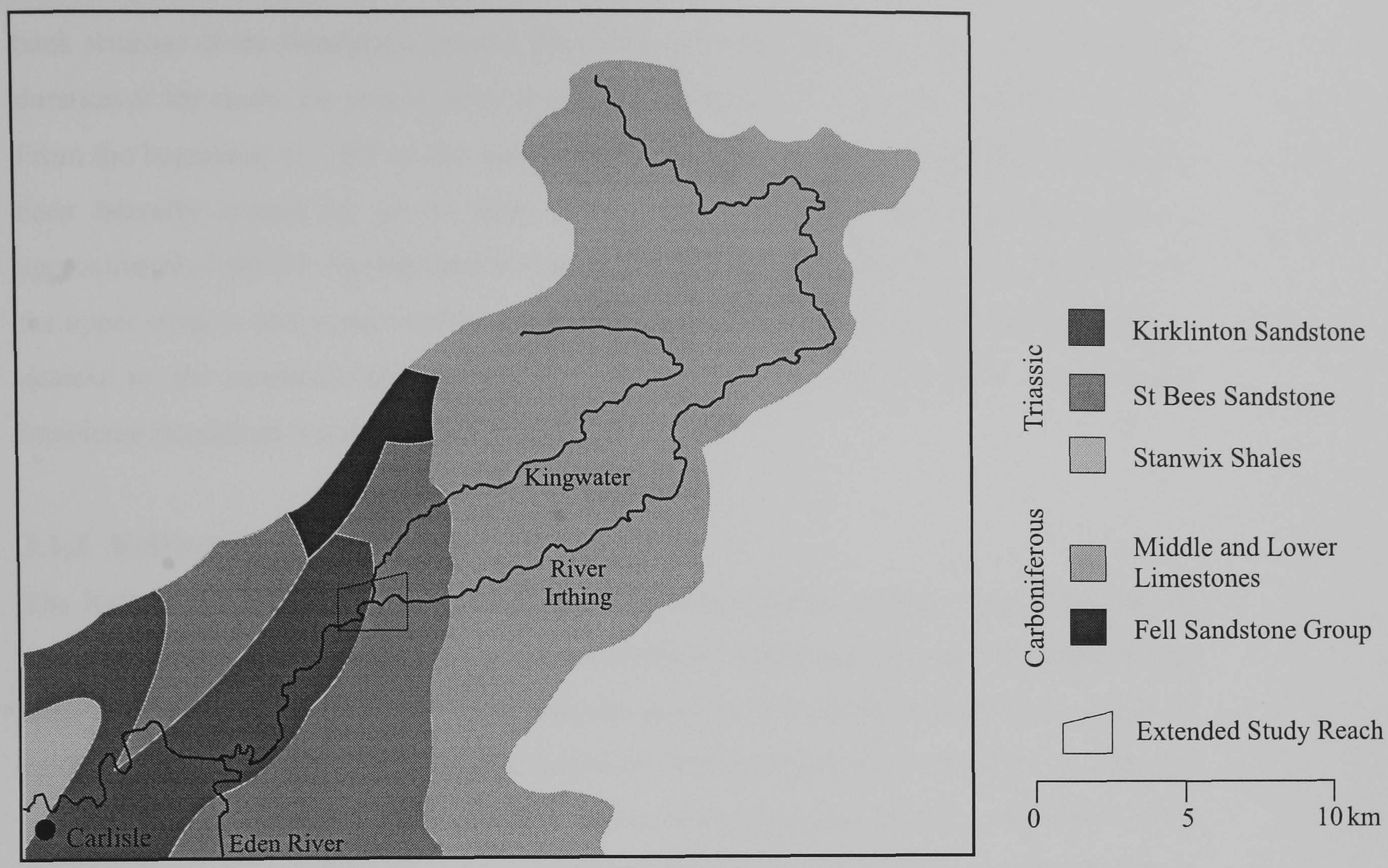
Dovecote Site Catchment

Kingwater Catchment

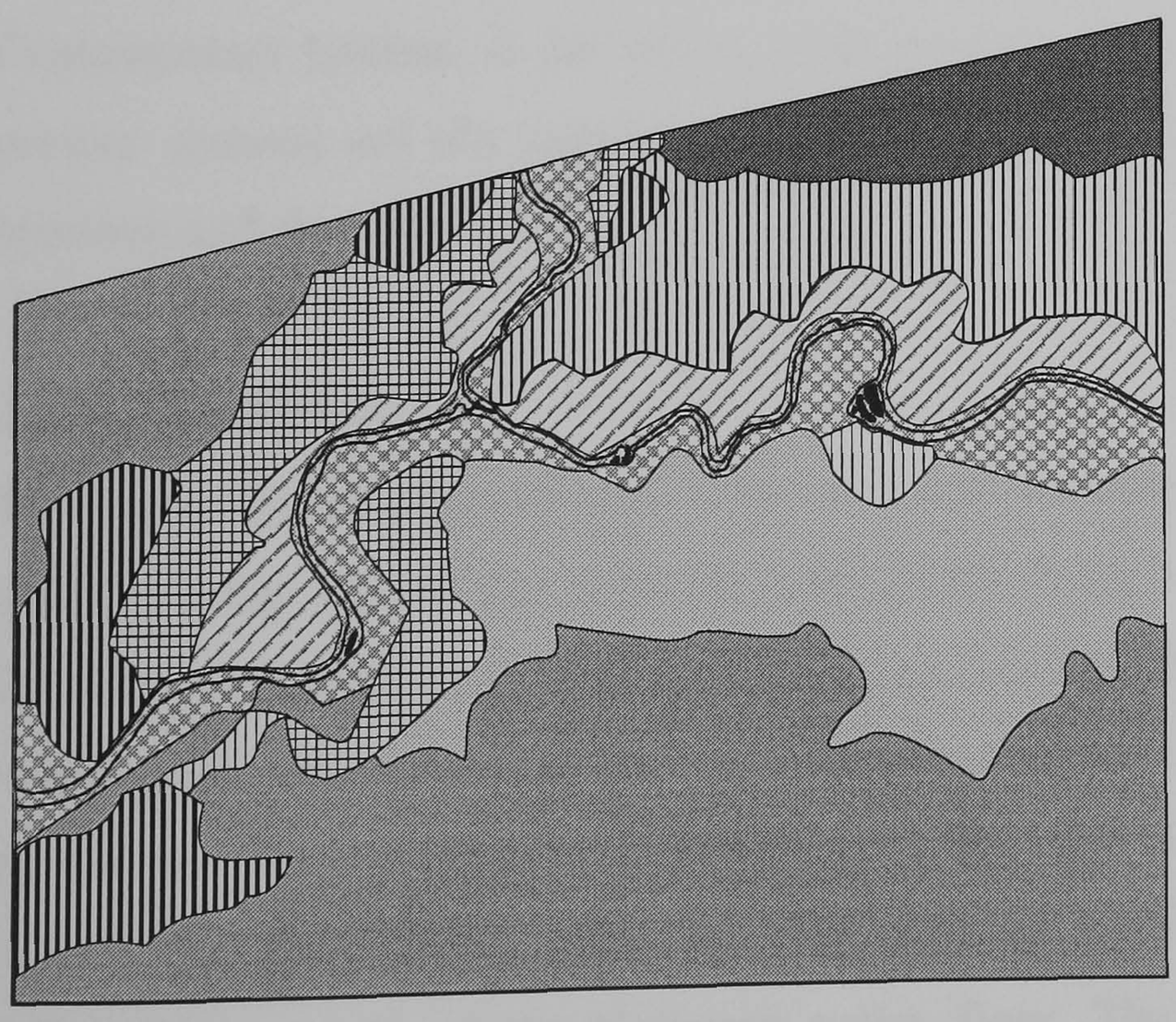
0 5 10 km

Figure 3.4

Catchment Geology Map



Drift Map of the Extended Study Reach



at the bottom of a steep terrace bluff on the northern edge of the valley floor. The exposed bank sections of the floodplain reveal 1.5m of coarse sands and gravels, into which over the duration of the study, the present river channel has progressively laterally eroded (Plate 3.2). From the beginning of 1997 to the summer of 1999, some sections are estimated as having been laterally eroded by up to three metres. The channel slope along the reach is approximately 0.00219. Present land use at the site includes low intensity crop cultivation on the upper terraces and pasture on the valley floor. Stretches of the lowest floodplain terraces, nearest to the contemporary channel, are enclosed and feature a dense, occasionally inundated floodplain woodland.

3.1.2 Kellwood

The Kellwood site covers a 1.4 km stretch of the River Irthing, drains a catchment area of approximately 220 km^2 which consists of the Dovecote catchment plus the catchment of the Kingwater tributary (Fig 3.3). The underlying geology is Kirklinton Sandstone; a fine to medium red, but locally white, Triassic sandstone. The overlying drift comprises of only one major valley floor terrace unit with both Pleistocene sands and gravels and boulder clay forming the northern valley sides (Fig 3.2). The valley floor is of variable width; being up to 1000m at its widest point and less than 500m wide where confined by glacial till on the southern valley side. The Kellwood reach displays a low relief below the steeper valley sides and a series of sinuous palaeochannel forms, most of which contained organic fill sediments. Some sections of the present channel along the Kellwood reach are slowly eroding with the lower part of the reach exhibiting the development of lateral and points bars due to fine sediment alluviation. The channel slope along the reach is approximately 0.00185. Contemporary landuse at the site is predominately livestock grazing. Sections close to the present channel are left ungrazed and there are a number of enclosed areas for pheasant breeding and shooting.

3.1.3 Breconhill

The Breconhill site, spanning a 2.5 km stretch of floodplain, lies opposite both the Kellwood and Dovecote site on the southern side of the River Irthing valley floor (Fig 3.3). The floodplain on the south side of the river is narrower than the northern side, possessing steeper valley sides. The underlying geology of the site consists of St Bee's Sandstone on the eastern part of the site and Kirklinton Sandstone on the west (Fig 3.4). The drift map reveals the presence of thick glacial laminated clay deposits, which form the steep valley sides and delineate the width of the Holocene valley floor. The downstream section of the reach possesses a number of flood basins containing over 2m of fibrous peat, while the upstream

section displays a number of fluvial terraces with sinuous palaeochannel forms. Upstream sections of the site presently display depositional bar features, whereas the river is actively laterally eroding the floodplain along the downstream sections. Present landuse is pasture while a densely vegetated oxbow lake of up to 1m in depth lies along the edge of the Holocene valley floor.

3.2 Regional Archaeological and Historical Records

3.2.1 Prehistoric archaeology

In his review of the archaeology of northern Cumbria, Blake (1959) noted that few prehistoric remains have been documented. This may relate to limited prehistoric activity in the region but equally from a bias towards wide research into the Romano British period and, specifically in lowland areas, the destruction of evidence by agricultural activity (Blake 1959, Bewley 1994). Evidence for the earliest phases of prehistoric human activity in Cumbria have been dated to 4000BC, with palaeoecological studies showing signs of patchy forest clearance (Walker 1966). Pennington (1970) and Bewley (1994) found evidence of Mesolithic and Neolithic anthropogenic activity concentrated on the Cumbrian coastline and on the Solway Plain respectively. Pennington (1970) also observed that vegetation change after 3000BC was no longer synchronous across the Lake District, implying the influence of factors alongside climate as initiators of change. Higham (1986) notes the significant variability in the magnitude of Mesolithic and Neolithic environmental disturbance between coastal regions, south west Cumbria, the Solway Plain and the Tyne catchment to the east.

Palaeoecological records derived from upland peat bogs in Northumberland (Davies & Turner 1979) and Cumbria (Walker 1966, Pennington 1970, Barber *et al.* 1994a, Dumayne & Barber 1994) show evidence for small temporary woodland clearances during the Bronze and early Iron Age. Walker (1966) considered this activity to be limited to higher ground leaving the valley floors undisturbed. An increase in landscape disturbance, due to an expansion of human population and activity, is thought to have occurred during the Iron Age (Higham 1986, Ralston 1999). A number of tribes are known to have inhabited northern England during the Iron Age, such as the Brigantes, although little is known about their socio-economic status (Barber *et al.* 1994). Their presence was investigated when archaeological research uncovered 50 settlements in northern Cumbria, which contained pottery dating to the third and fourth centuries BC (Blake 1959). Work on upland peat bogs in the region has

Plate 3.2 Evidence for contemporary lateral erosion along the Dovecote reach

1) undercutting of river banks during high discharge

2) erosion of uncohesive glacial sediments

shown the significant acceleration of human activity up to the time of Roman occupation (Barber *et al.* 1994b, Dumayne & Barber 1994, Dumayne-Peaty & Barber 1997). Clearances during the early part of the second century BC have also been detected in upland sites in eastern Cumbria (Higham 1986).

The limited archaeological evidence for settlement and activity up to the early Iron Age correlates with the palaeoecological record which depicts a forested landscape with small temporary clearances (Dumayne & Barber 1994). Some researchers, however, still believe that the neglect of the prehistoric in favour of research into the Romano-British period may have created bias in the archaeological record (Bewley 1994, McCarthy 1995). In particular, the limited amount of documented prehistoric settlement and activity in northern Cumbria has resulted in the area being classified as a social and economic backwater compared with its southern counterparts (McCarthy 1997). Further work is required therefore to improve the understanding of prehistoric anthropogenic activity and environmental change in both the northern and western parts of Cumbria.

Having reviewed the prehistoric archaeological research in Cumbria, a spatial bias towards the Lake District, peatlands and coastal areas is evident. The work of Pennington (1970, 1975) for example concentrates on the Lake District and the Cumbrian coastline. Bewley (1994) concentrated his research on the Solway Plain. The palaeoenvironmental analyses undertaken by researchers on ombrotrophic bogs provide a reconstruction of changes in the uplands of Cumbria (Walker 1966, Barber *et al.* 1993, 1994a, 1994b, Dumayne & Barber 1994, Mauquoy & Barber 1999a). Therefore, valley floor environments throughout Cumbria are relatively unresearched (McCarthy 1995).

3.2.2 The Romano-British period

The presence of the Romans in northern Britain has been extensively investigated with original work concentrating on finding the location of settlements, and military centres, based on archaeological artefacts and evidence of constructions (Huntley & Stallibrass 1995). Information regarding the impact of the Roman presence in northern Cumbria therefore came from a socio-economic direction (McCarthy 1995). The presence of the Romans, however, has great significance when evaluating the changing nature of the landscape. The significance of their activities in northern Cumbria is accentuated by the assumption that the indigenous population was less advanced agriculturally and technologically than their southern counterparts (McCarthy 1997).

The Roman armies arrived in northern England around 80AD, with the construction of Hadrian's Wall beginning in 120AD (Breeze 1982). Hadrian's Wall crosses the River Irthing at Birdoswald Roman fort, to the east of which the wall was initially constructed in stone whereas to the west the wall was first constructed with turf and clay, and later rebuilt in stone (Breeze 1982). The magnitude and timing of Iron Age and subsequent Roman activity and its impact on the environment in Cumbria, specifically around the area of Hadrian's Wall, has been studied and debated for decades. Barber (1981) was the first to provide palaeoecological evidence for the widespread deforestation and vegetation changes that occurred 2000 years ago. Subsequent research has verified the original findings but the characteristics of the extent and timing of the clearances, particularly with respect to whether they were initiated in the late Iron Age or during the Roman occupation, are still debated (e.g. Dumayne & Barber 1994, Dumayne-Peaty & Barber 1997, McCarthy 1995, 1997, Manning *et al.* 1997). The route of Hadrian's Walls runs across the northern valley sides of both Kellwood and Dovecote field sites, approximately 500m from the present river channel.

3.2.3 Early Medieval history to the present

From an evaluation of anthropogenic and environmental changes along the English-Scottish border areas during historic times, Banks (1977) concluded that it was an area which had experienced little fundamental change. Following the initial impact of the Roman occupation further woodland clearances resulting from population resettlement after an acceptance of Roman occupation have been seen from palynological data from Walton Moss (Dumayne & Barber 1994, Dumayne 1995). Little is known about the nature or patterns of Anglo-Saxon human activity following the departure of the Romans. It is assumed, however, that agriculture and settlement established during the Romano-British period experienced only minor changes up to the Medieval period (Walker 1966).

The Medieval period brought about a massive expansion of monastic settlements in northern England (Winchester 1987). Lanercost Priory, one kilometre upstream of the Dovecote and Kellwood sites, was established in 1166 (Banks 1977). Associated with monastic settlement was an increase in woodland clearance as its influence on agriculture effected an expansion of sheep farming, and subsequently overgrazing and upland woodland clearances (Pennington 1970). Winchester (1987) notes, however, that despite an increase in clearances during the Medieval period, the existence of large estates from the Feudal system resulted in the preservation of extensive wooded areas for hunting.

3.3 Regional Environmental Change

The River Irthing catchment lies within Devensian glacial limits and hence the river system developed during the ice sheet retreat between 16,000 and 10,000BP in north west England (Harvey 1985). Due to an absence of research into the alluvial histories of either the River Eden or River Irthing no information regarding Holocene floodplain evolution is available. However, documentary evidence for enhanced fluvial activity in the River Irthing and Eden catchments follows the onset of the Little Ice Age. Mawson (1979) has documented the historical evidence for fluvial change along the River Irthing near to Lanercost Priory. In particular, he notes the presence of two bridges existing between the 17th and 19th centuries, one being at the site of the present channel and one being 90m to the north. This suggests that the reach was formerly divided. Mawson found evidence of frequent late 17th century flooding along the reach, which prompted the strengthening of channel banks and building of weirs. In 1701 floods removed a bridge at Lanercost which was replaced in 1724. Pictoral and cartographic evidence of the new bridge shows the infilled former northern arm of the channel, thus revealing the abandonment of the anabranch arm of the River Irthing during the late 17th and early 18th century floods. Following the high magnitude flooding of the 18th century, Archer (1992) documents large flood events within the river catchments in Northumberland, County Durham and the western Pennines. A comparable chronology of flooding has not been documented for northern Cumbria.

In 1771, extreme flood events were documented in the major catchment systems of northern England (Archer 1992). The floods destroyed many bridges on the eastern side of the Pennines and Northumberland, although those on the western side survived (Mawson 1979). Cartographic evidence of the River Eden at Carlisle shows the effects of these floods. Prior to the late 18th century floods, maps show the River Eden at Carlisle to be anabranched around an island called The Sands (Richards 1685, Map of Soccage Lands at Carlisle 1752). A map of 1797 depicts a small chute channel running through The Sands. Wood's 1812 map of Carlisle shows the Sands Island has been replaced by a single thread channel through Carlisle, most probably as a response to the flooding.

3.3.1 Climate records

Research into Holocene climate change and human activity has been conducted on ombrotrophic bogs in northern Cumbria over the past 20 years (e.g. Barber 1981, Haslam 1987, Stoneman 1993, Barber *et al.* 1994a, 1994b). Two of the bogs utilised for this research, Bolton Fell Moss and Walton Moss lie 4km and 2.5km respectively from the Kellwood and Dovecote field sites (Fig 3.2). Data from the bogs therefore provides an excellent proxy

climate change record for comparison with environmental changes seen on the River Irthing valley floor (Brown 1997a, Section 2.2.2).

Barber (1981), *via* analysis of *Sphagnum* and peat humification at Bolton Fell Moss put forward the Phasic Theory of peat growth which argued that bog growth, in contrast to previous peat regeneration theories, was subject to climatic forcing. Subsequent research using plant macrofossil and pollen data from peat cores has identified Holocene wet and dry climatic shifts initiated by changes in effective precipitation. Barber *et al.* (1994a), for example, identified five wet and three dry climatic shifts dating from 1600BC to present from Bolton Fell Moss macrofossil records. Older climatic deteriorations have also been identified, such as at 2000BC for which a wetter climate has been noted from bogs in northern Cumbria and southern Scotland (Stoneman 1993). Another significant climatic deterioration c.1400AD, associated with the Little Ice Age (Roberts 1989), has been found at sites within the River Irthing catchment (Mauquoy & Barber 1999b).

Chapter 4

Methods

This chapter describes the methodological approach and techniques applied to meet the objectives outlined in Chapter 1. Firstly the methods employed to find a suitable reach for detailed investigation are explained. The technique of analysing recent and historical channel change through cartographic sources and aerial photographs is described in Section 4.2. Methods employed for the assessment of floodplain geomorphology and floodplain sedimentary characteristics are discussed in Sections 4.3 and 4.4 respectively. The approach taken for plant macrofossil analysis, including preparation and counting procedures and issues of interpretation, are described in Section 4.5.

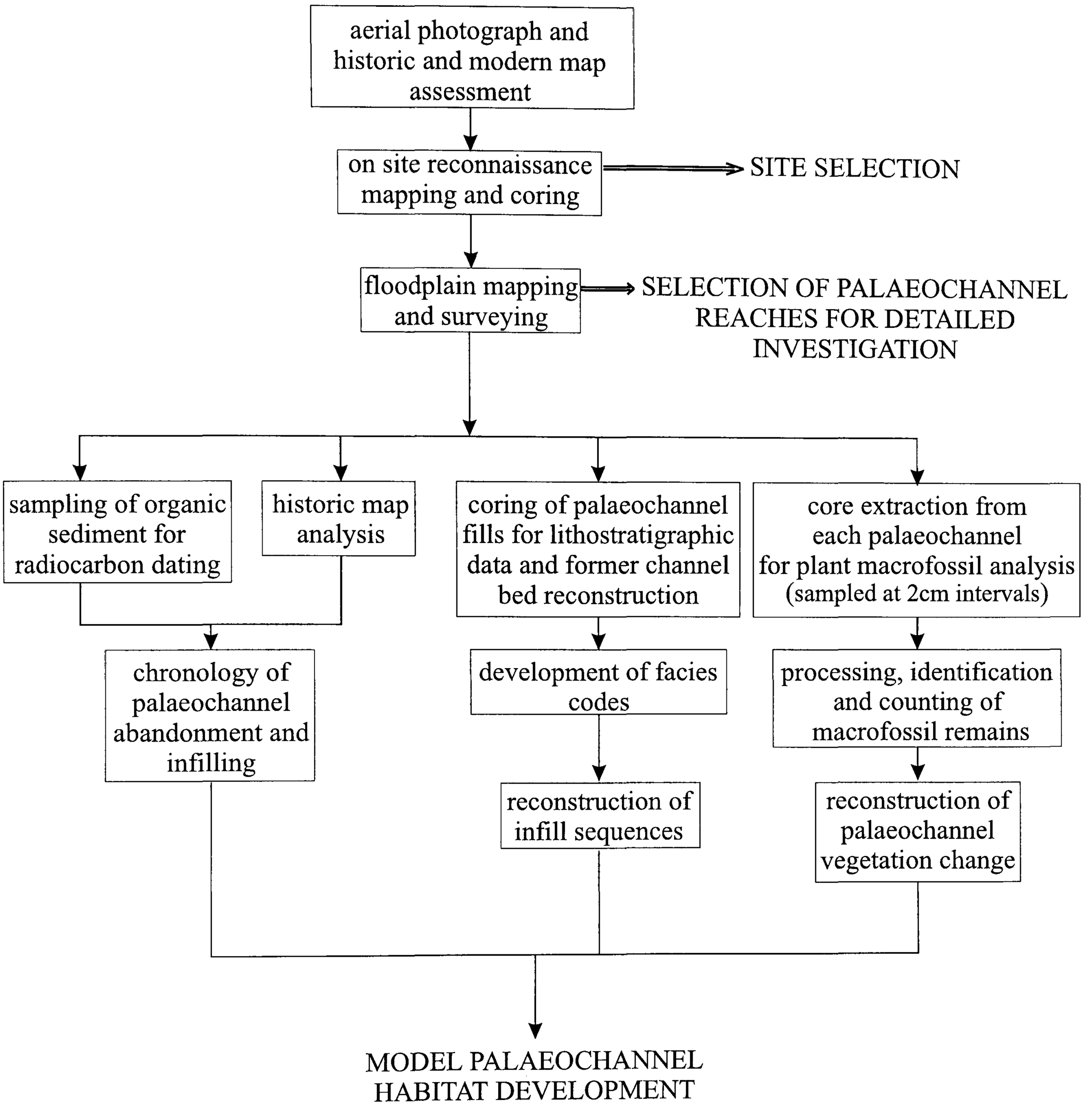
The methodological approach to the research was based upon the technique developed by Amoros *et al.* (1987) to investigate temporal and spatial floodplain dynamics (Section 2.3.3). This requires a reconstruction of late Holocene vegetation communities which are to be compared with contemporary floodplain community characteristics in order to ascertain the characteristics of and forcings behind biotic change. The palaeoecological data are provided by plant macrofossil analysis of organic palaeochannel sediments in the study reach, while the contemporary data are provided by published accounts of floodplain vegetation (e.g. Grime *et al.* 1988, 1990, Bornette *et al.* 1994a, 1994d, Rodwell 1995). The methods also incorporate the geomorphological and hydrological dynamics of the study reach *via* the reach scale reconstruction of Holocene and historic valley floor development and by sedimentological and morphological analyses at the scale of individual palaeochannels. Chronological control of palaeochannel development is provided by radiocarbon dating of organic sediments and cartographic evidence for channel change. The array of techniques used for this research is represented in Figure 4.1.

4.1 Site Selection

Finding a suitable site for research within the region entailed the assessment of large scale maps to locate reaches of the River Eden and its tributaries with wide valley floors and evidence for former channel change. Evidence for the latter on Ordnance Survey maps includes parish boundaries, which often follow the former routes of river channels, oxbow lakes or areas of marsh land and geomorphological features depicting instability (e.g. gravel bars and middle channel islands). Sites identified were thus visited and reconnaissance

Methodology

Figure 4.1



mapping and coring undertaken to assess the number and quality of well preserved river terraces and associated palaeochannels with organic fills. An extended reach of the River Irthing was selected for investigation on the basis of the quality and quantity of the aforementioned features.

4.2 Cartographic Analysis

Historic cartographic data was obtained from maps held at the Department of Geography, University of Newcastle and at the Cumbria County Records Office, Carlisle. Historical maps available included a map of the County of Cumberland, surveyed in 1770/1771 and published in 1783, and a Cumberland County map surveyed in 1821/1822. Ordnance Survey maps were available for survey dates *circa* 1840, 1951 and 1982. The dates, scales and names of the maps used within the research are detailed in Table 4.1.

Table 4.1 Details of maps and aerial photographs used to evaluate historic river channel change and surface floodplain geomorphology

Map title	**Publication date**	**Date surveyed**	**Scale**
The County of Cumberland	1st Edition 1783	1770-1771	60 miles to a degree
New Map of Cumberland divided into 5 wards	1829	1821-1822	c.1 inch: 3 miles
1st Edition Ordnance Survey Map	1850	c.1840	6 inches: 1 mile
NY 56 SW	1952	c.1930	1:10,560
Aerial photograph	1951	1951	1:7500
Aerial photograph	1971	1971	1:10,000
NY 45/56	1982	1972-1974	1:25,000

Each map and aerial photograph from Table 4.1 was scanned. The images were imported into Corel Draw and manipulated to a common scale, using features common to each map including a bridge at the lower end of the extended reach, the confluence of the River Irthing and Kingwater and the farm buildings at the Kellwood site. The outline of the river channel and geomorphological and ecological features, including bars, wetlands and oxbow lakes were then traced in Corel Draw (e.g. Fig 5.7 and Fig 6.6). Analysis of a succession of river channel outlines located reaches experiencing lateral channel change, avulsion, and sedimentation i.e. bar form changes, the analysis of which acknowledged the variations in scale and geomorphological accuracy between the different maps (cf. Hooke & Redmond 1989, Passmore *et al.* 1993).

4.3 Floodplain Geomorphology

Detailed geomorphological mapping was undertaken at the Kellwood and Dovecote sites on the northern side of the river and at Breconhill on the southern side of the River Irthing floodplain using aerial photographs and 1:10,560 Ordnance Survey maps as base maps. Two sets of aerial photographs dating to 1952 and 1971 were available for the extended reach. Geomorphological mapping determined discrete terrace units, the terrace edges and associated palaeochannel and depositional bar features. The planform morphology of palaeochannel reaches was mapped and surveyed. Spot heights on terraces surfaces and valley cross sections at each site were surveyed using a TC400 survey station in order to establish a relative terrace height, an estimate of the magnitude of Holocene valley floor incision, and enable cross-valley correlation of terrace units.

4.4 Sedimentary Analysis

Sediment cores were taken at all sites, at the apex of former river channel meander bends, along palaeochannel thalwags and within flood basins to establish the location of well preserved organic palaeochannel fills. As a result of the reconnaissance coring five palaeochannel sections were selected for more detailed analysis, primarily on the basis of organic preservation and length of palaeochannel reach preserved. The sections from the geomorphological mapping were also considered to span a range of ages and reflect variable geomorphological features, based on the different terrace units and floodplain planform morphology. Three of the palaeochannels, DC2, DC4 and DC7, were located at the Dovecote site, with the remaining two, KW1 and KW2, located at the Kellwood site.

Fine grained palaeochannel fills in each of the five palaeochannels were cored using a sand auger with a 0.5m length chamber. Coring was conducted at 2m intervals along five equally spaced transects with each core terminated on reaching coarse gravels, bedrock or till. The sedimentary characteristics including modal grain size (qualitatively assessed by comparison with a transparent grain size card), structure, colour, organic content and depth of erosional surfaces and horizon changes within each core were logged. Intermediate transects were also cored at 2m intervals in order to determine depth of fine grained sedimentary infills and thereby aid the development of a high resolution three dimensional image of gravel bed morphology. Each coring location was surveyed with a TC400 survey station. Distance between the first and fifth transect was determined by estimating the former channel width from the surface geomorphology, in order to incorporate a riffle-pool-riffle sequence based upon a 1:7 width:riffle/pool spacing, calculated from Hey & Thorne (1986) whereby riffle to riffle distance is equal to '*2*channel width*π*' .

Channel bed morphology, based on the depth of channel fill to gravel, bedrock or till along each transect was analysed using the 'Surfer' graphics program which generates a three dimensional surface from x, y and z point data. The three dimensional surface morphology was thus used to establish the location and sizes of geomorphological 'patches' (such as pools and riffles), which can influence the spatial variability in channel infilling, including for example the lateral persistence of stratigraphic discontinuities, and the development of vegetation communities (Frissel *et al.* 1986).

Table 4.2 Classification of lithofacies units from the palaeochannel fills and floodplain sediments. Facies codes correspond to those described in Chapters 5 and 6.

Sediment description*	**Associated lithofacies from Miall (1978)**	**Interpretation****	**Facies Code**
Coarse sand and massive gravel	Massive or crudely bedded gravel	Glacio-fluvial or Holocene channel bed sediment	**Gm**
Structureless, homogenous clay	Diamicton mud	Unlithified low energy deposit, possibly lacustrine	**Dmm**
Weathered bedrock	-	Triassic sandstone	**L**
Coarse-medium sands. Cross bedded (across 2-D palaeochannel transects)	Sand, medium to coarse, solitary or grouped planar cross beds	Transverse bars, lateral accretion deposits, lower flow regime	**Sp**
Coarse to medium sands, massive	-	Bed load deposits	**Sp-p**
Medium, fine-medium and fine sand, laminated	Sand, very fine to coarse, horizontal lamination	Lower and upper flow regime, including possible runoff deposits	**Sh**
Finely laminated clays and silts	Mud, silt, possible desiccation cracks	Overbank suspended sediment deposits	**Fm**
Fine to medium sands with silt/organic/fine sand lenses	Sand, silt, mud, fine lamination	Waning flood deposits, backwater inputs	**Fl**
Clays and silts with organic inclusions	Silt, mud, laminated to massive	Backswamp deposits	**Fsc**
Peaty silt, peaty fine sands, peats	Peat, carbonaceous mud with organic inclusions	Swamp deposits, floodplain mire	**C**
Top soil with pedogenic structures	Carbonate with pedogenic features	Soil	**P**

* Sediment description is based on the core log data
** Interpretation is based on combined data from Miall's lithofacies coding system, interpretations of Lewin (1992) and from data collected during the present study.

Fine grained channel fills were assessed by correlation between cores to produce two dimensional images of infill sediments (cf Erskine *et al.* 1992, Starkel *et al.* 1996), followed by a determination and analysis of facies units. Division of palaeochannel fills into units or 'facies' (see Section 2.2.3.2) was undertaken from analysis of sedimentary characteristics

and depositional patterns. Each facies represented specific periods of sediment accumulation, depositional process and palaeochannel environmental conditions (cf Lewin 1992). These 'lithofacies types' (Miall 1978) are described in Table 4.2, incorporating the dominant sedimentary characteristics used to subdivide the palaeochannel fill, the equivalent lithofacies unit, as described by previous authors (e.g. Miall 1978, Lewin 1992, Jones *et al.* 1999), and the environmental conditions and processes inferred by each facies. The classification is used in Chapters 5 and 6 to describe and interpret the palaeochannel fill sediments.

4.5 Plant Macrofossil Analysis

A single core was extracted for plant macrofossil analysis from each channel, using either a Cobra/Stitz piston corer or a Russian corer according to the softness of the ground. Cores were taken from the deepest sections of the channel in order to maximise the length and resolution of the macrofossil record. Each macrofossil core was described and sampled at 2cm intervals. Where cores were taken using Russian coring techniques, cores were removed to the laboratory for sampling. Cores extracted using the Cobra/Stitz piston corer were sampled on site and retained in sealed plastic bags.

The preparation of sediment for plant macrofossil analysis followed standard techniques (Dickson 1970, Watts 1978, Birks 1980, Mannion 1986a). Samples were dissolved in water to establish the volume of material and to disaggregate the material. Samples with a high silt/clay content were disaggregated in 10% sodium hydroxide (NaOH). Each sample was sieved through a 125μ mesh, with the remaining contents transferred to a beaker containing distilled water. These were scanned with a low power binocular microscope, and all identifiable botanical remains extracted and identified using modern and published reference material. Published identification guides included Martin (1951), Martin & Barkley (1961), Nilsson & Hjelmquist (1967), Montgomery (1977), Musil (1980), Tutin (1980), Lousley & Kent (1981) and Tomlinson (1985). Modern reference material was held at the Department of Archaeology, University of Durham.

The results were calculated as number of seeds per volume of sediment (cf. Birks 1980). Also noted and included in the macrofossil data were degraded seeds, wood and charcoal fragments, limnic fauna, bud scales and bryophyte fragments (mosses and liverworts). Figures were then rounded to provide a total per 50ml of sediment to enable comparison within and between cores. Results were drawn up using Tilia, version 2.0 and Tilia Graph version 2.0 (Grimm 1987). Species nomenclature follows Stace (1997) with the species

grouped into six categories; aquatic, grassland, ruderal, wetland, wide niche and woodland, based upon ecological data from Perring & Walters (1976), Grime *et al.* (1988, 1990), and Stace (1997). Interpretation acknowledged that some species can be found in more than one type of environment. Due to differential preservation of botanical remains, there is a variation in the taxonomic accuracy to which seeds were identified. Following Watts & Winter (1966), a full species name infers a reliable identification of a macrofossil. When only the generic or family name is provided identification to a lower taxon cannot be made due to conditions of preservation. The usage of 'type' relates to a macrofossil whose morphology matches more than one species. The prefix 'cf.' infers that a macrofossil resembles a species but a degree of uncertainty remains.

The macrofossil data was zoned according to predominant species trends. Each zone was thus compared with published data of British vegetation communities (Rodwell 1992, 1995) and other published contemporary floodplain vegetation records (e.g. Bornette & Amoros 1991b, 1996, Bornette *et al.* 1994a, 1994d, 1998a, Henry *et al.* 1994, Wassen *et al.* 1990).

4.5.1 Taphonomic issues

Interpretation of plant macrofossil data with regard to taphonomy was based upon four aspects linked to the issues discussed in section 2.4.4. Firstly, differential productivity of the species present, resulting from vegetative reproduction and ecological characteristics, was accounted for *via* the application of information from autoecological records (Grime *et al.* 1988, 1990). Secondly, problems relating to long distance dispersal and reworking of macrofossils were addressed via the analysis of the sedimentary context of deposition and burial. The third taphonomic issue related to species presence within the core, whereby analysis of the macrofossil data incorporated species patterns in order to account for species which had only a singular or sporadic presence. The numbers of species present has also been interpreted with respect to whether the species deposited a seed bank. Lastly, the taphonomy of macrofossil species was assessed *via* observations of degraded and durable seeds. The presence of highly degraded, unidentifiable macrofossils was linked to long distance transport prior to deposition (cf Brown 1997a) which could then be incorporated with the sedimentological data for interpretation. In addition species whose habitat niche was anomalous when compared to the other species within the same level, were considered to have potentially been transported prior to deposition.

4.6 Organic Matter Content

The organic content of each layer was determined *via* loss on ignition (Goudie 1994). Material from each layer sampled for macrofossil analysis was dried, weighed and heated to 500°C for 8 hours to remove all combustible material. Samples were then re-weighed and the percentage loss calculated.

4.7 Radiocarbon Dating

A relative chronology of terraces across the floodplain was established *via* geomorphological mapping and surveying. Radiocarbon dates were obtained from organic basal sediments from channels DC2, DC4, and KW2 to provide an indication of the timing of channel abandonment. A date was also obtained from near to the surface of palaeochannel KW2 in order to assess the chronology of infilling and timing of vegetation change (with reference to the plant macrofossil record). It is acknowledged that having a small number of dates limits the resolution at which the chronology of infilling and corresponding macrofossil record can be assessed. Channels DC7 and KW1 did not require radiocarbon dates as the timing of channel cut off and commencement of infilling could be established from cartographic data. Material for radiocarbon dating was sent to Beta Analytic laboratories, Florida. Radiocarbon dates are referred to in the text as BC/AD having being calibrated with reference to Stuiver *et al.* (1993).

Chapter 5

Results & Analysis: Dovecote Site

The Dovecote study site incorporates a 1.2 km reach of the northern side of the River Irthing floodplain, upstream of the Kingwater tributary (Fig 3.1). The site extends across 600 m of the 800 m wide valley floor (Fig 5.1), drains a catchment of 170 km^2 and has a gradient of 0.00219. The results of floodplain geomorphological mapping and surveying of the Holocene valley floor at Dovecote are detailed in Section 5.1. Following assessment of the floodplain geomorphology three palaeochannel reaches: DC2, DC4 and DC7 (Fig 5.1) were selected for detailed investigation. The results of sedimentological and plant macrofossil analyses for each palaeochannel are detailed in Sections 5.2, 5.3 and 5.4.

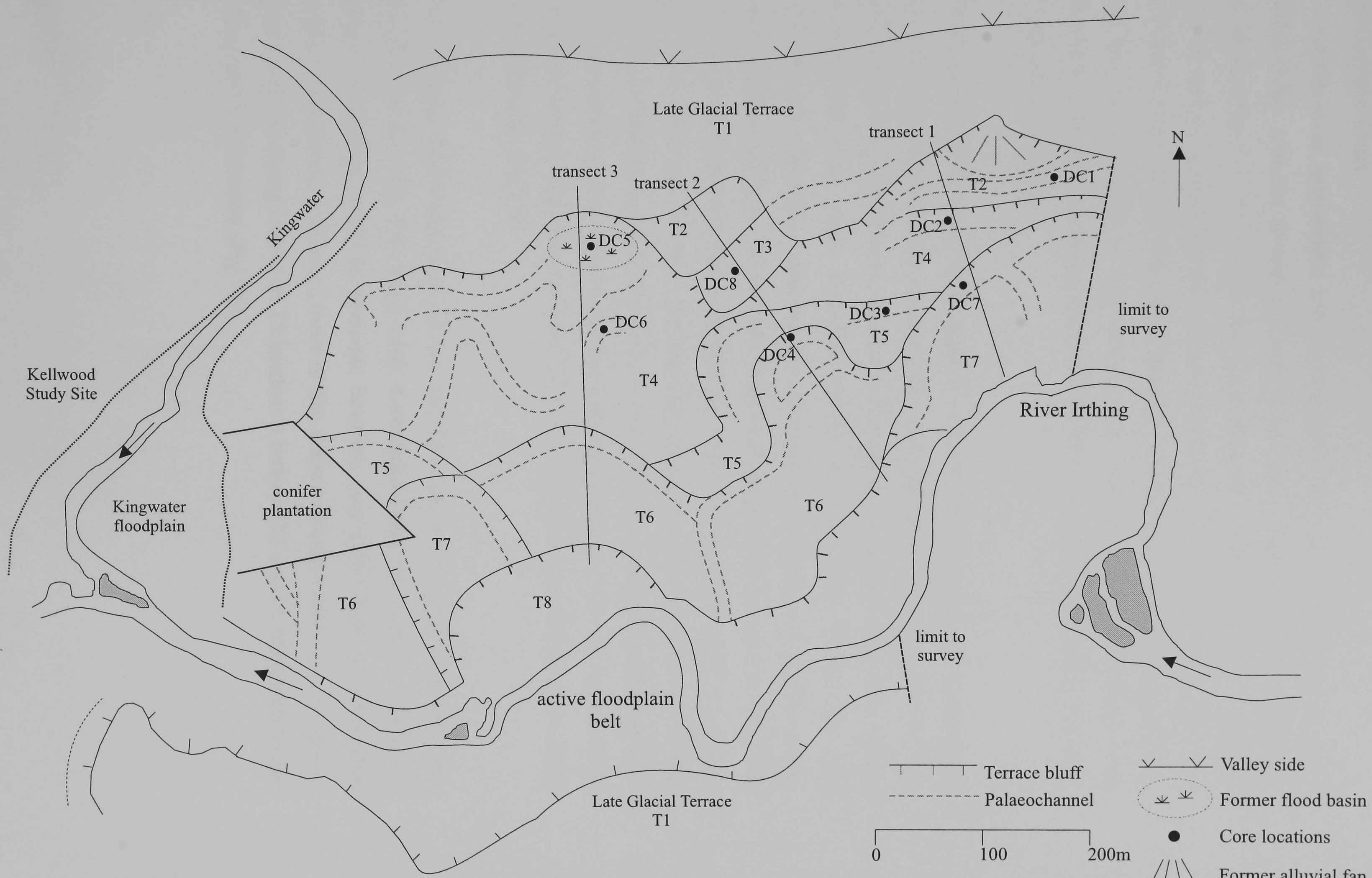
5.1 Floodplain Geomorphology

The surface geomorphology of the Dovecote reach reveals a well preserved sequence of eight fluvial terraces (termed T1-T8) and associated palaeochannels (Fig 5.1). A tabulated list of terrace units, including heights above the present river channel bed and approximate timing of abandonment where known, followed by a description of each terrace, is provided below.

Table 5.1 - Fluvial terrace heights and dates at the Dovecote site

Terrace	Height above channel bed (m)	Dating Control
T1	6.5	late glacial (inferred)
T2	5.0	-
T3	4.0	-
T4	3.0	2440-1920cal BC (3750 ±60BP) (bulk radiocarbon date from palaeochannel basal sediments)
T5	2.5	-
T6	2.5	1410-1620cal AD (460 ±60BP) (bulk radiocarbon date from palaeochannel basal sediments)
T7	2.5	1771-1822AD (historic maps)
T8	1.0	1951-1971AD (recent maps and aerial photographs)

Dovecote Floodplain Geomorphological Map



Dovecote Terrace Units

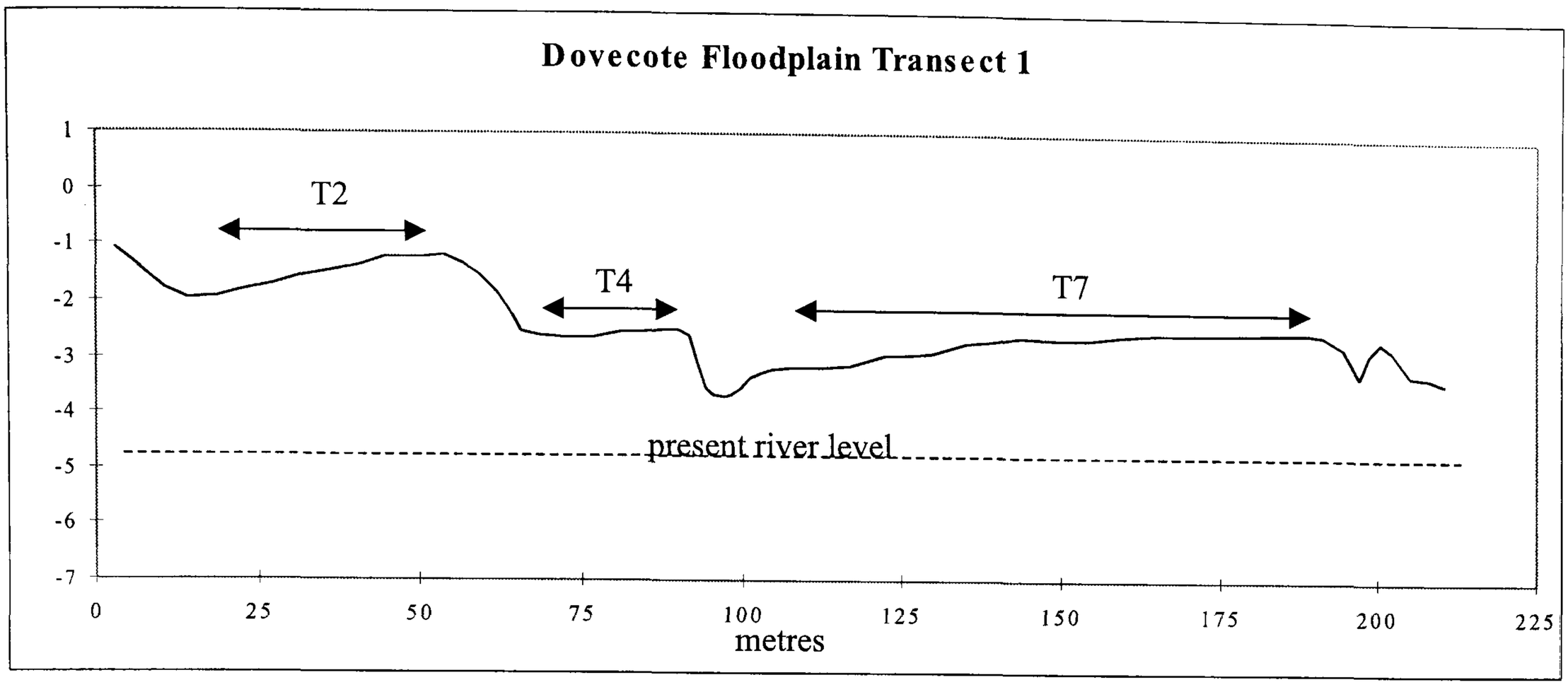
T1 T1 extends in an approximate east-west direction along the north side of the River Irthing valley, with the downstream limit of the terrace delineated by the Kingwater floodplain (Fig 5.1). The terrace lies 6.5m above the present river bed, exhibits a variable surface morphology and a steep terrace bluff to the lower terrace units (Fig 5.2), and is composed of a thin top soil layer overlying coarse gravel and sand deposits. The unit is comparable to high terrace units elsewhere in upland British river catchments, which are attributed to late glacial fluvial activity (Harvey 1985, Passmore & Macklin 1997; 2000).

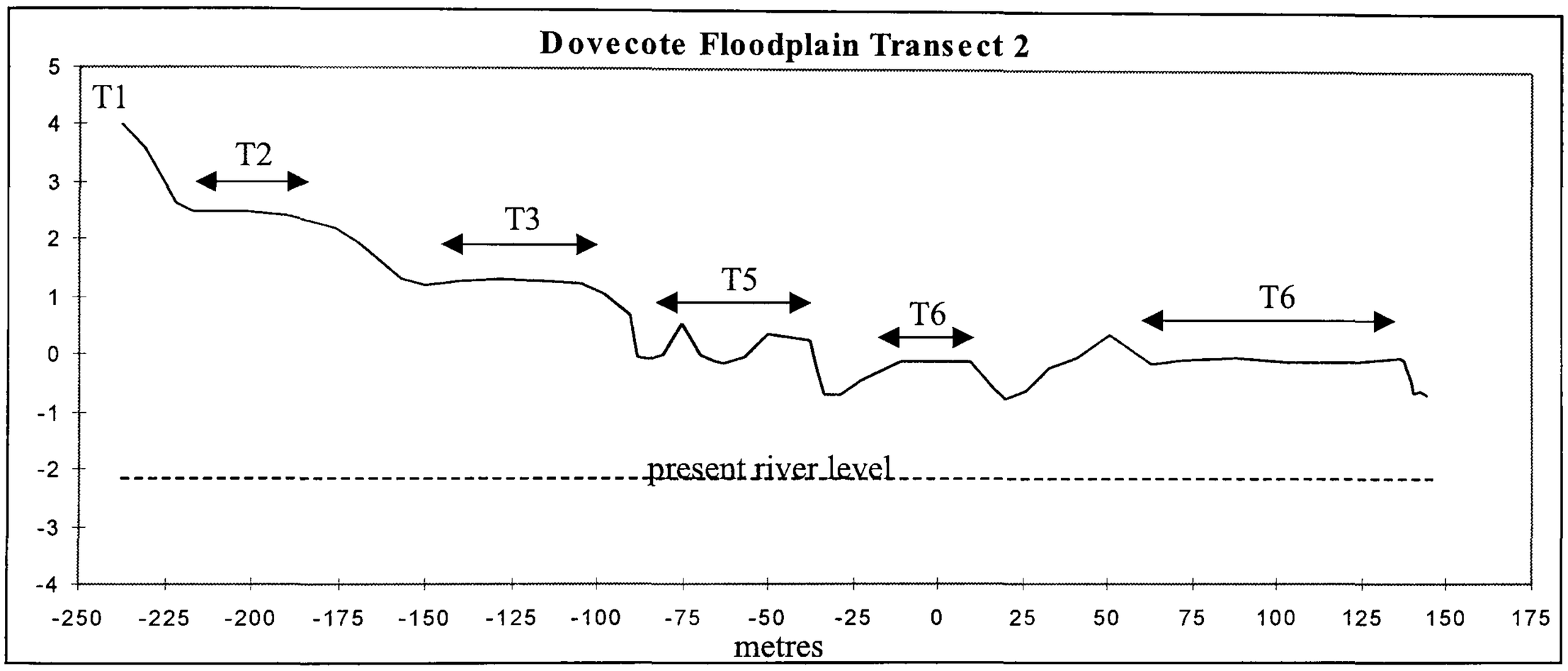
T2 Two fragments of T2 lying 1.5-2m below T1 and c.5m above the active river bed, have been preserved (Fig 5.1). The upstream part of the unit is overlain by an alluvial fan, associated with a small tributary stream extending from the upper T1 unit and a surface palaeochannel form which meanders around the lower edge of the fan. The palaeochannel stratigraphy comprised of a well mottled clayey top soil, with increasing organic matter content to 130cm, and a large wood fragment at 120cm (core DC1; Fig 5.3). The palaeochannel gravel bed height lies 4m below the gravels of T1, at a similar level to the lower unit T3, but c1.5m above the palaeochannel gravel bed height of unit T4. The downstream segment of the unit, is a smaller terrace fragment possessing little surface morphology (Fig 5.1). The terrace lacks direct dating control but lies below the late glacial terrace and above the dated T4 terrace unit and hence is bracketed as early to mid Holocene (Fig 5.6).

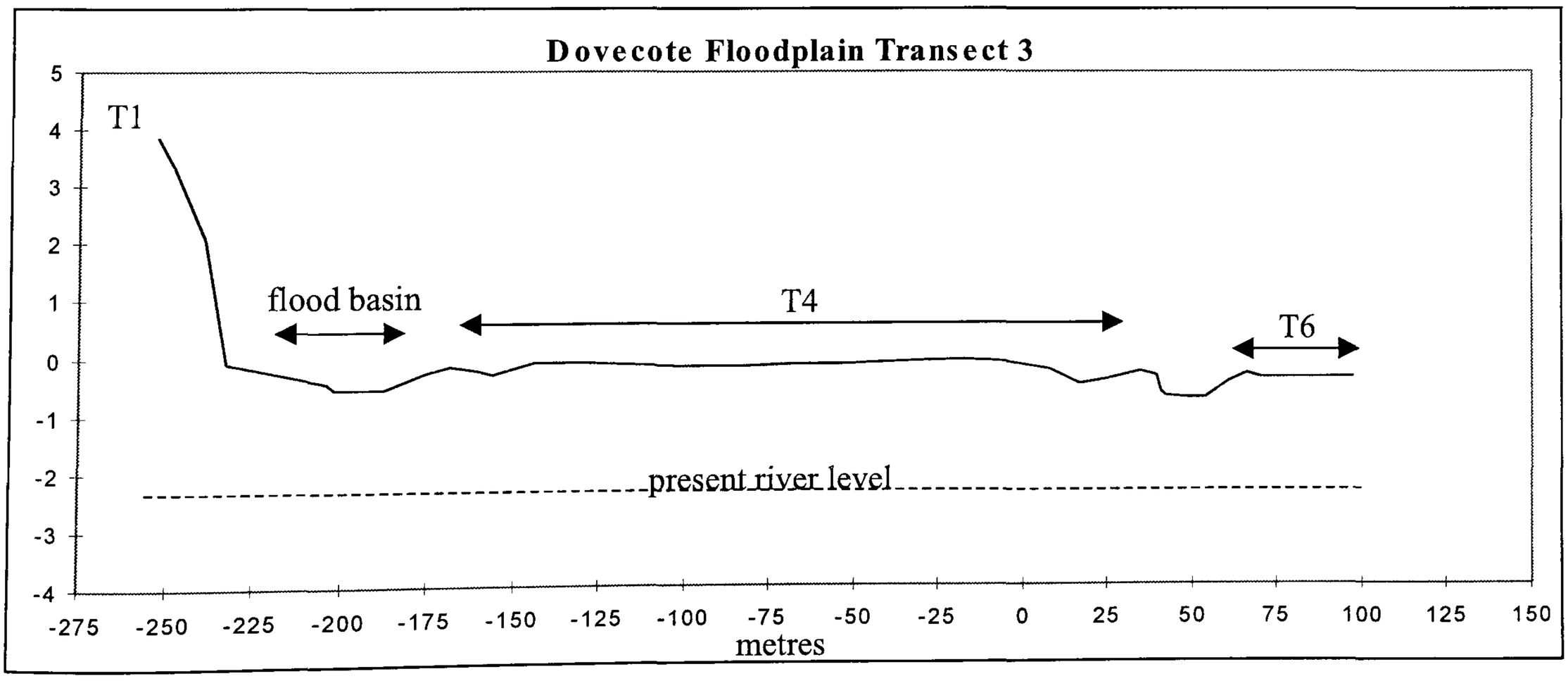
T3 Only a single small fragment of terrace unit T3 is preserved, lying 4.1m above the present river bed (Fig 5.4). Farm track disturbance limits the extent to which the surface morphology could be analysed, however, core DC8, from an undisturbed section of the terrace, indicates a metre of fine grained sediment above a coarse gravel surface. Indirect dating control on T3 brackets it between T2 and T4, suggesting an age in the early-mid Holocene (Fig 5.6).

Dovecote Cross Section Profiles

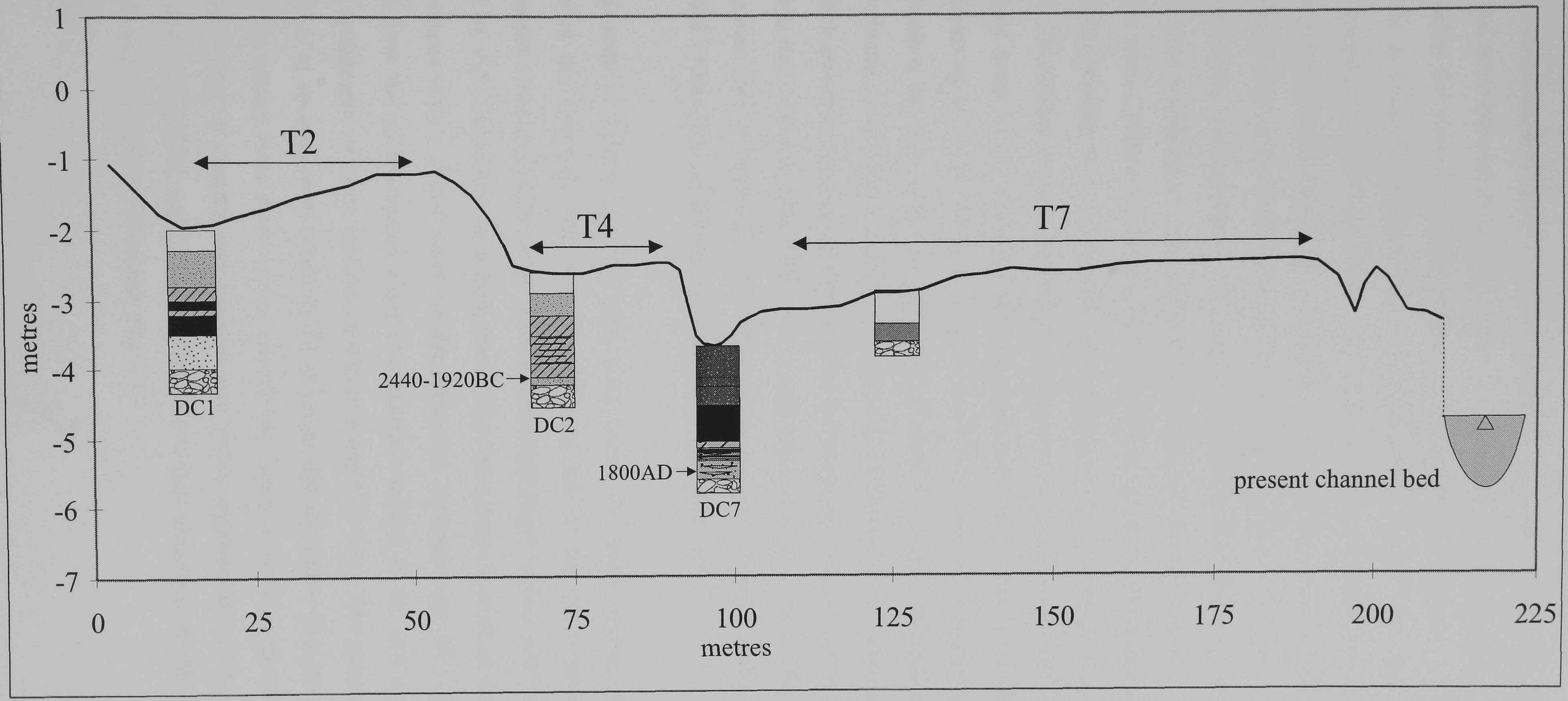
Figure 5.2

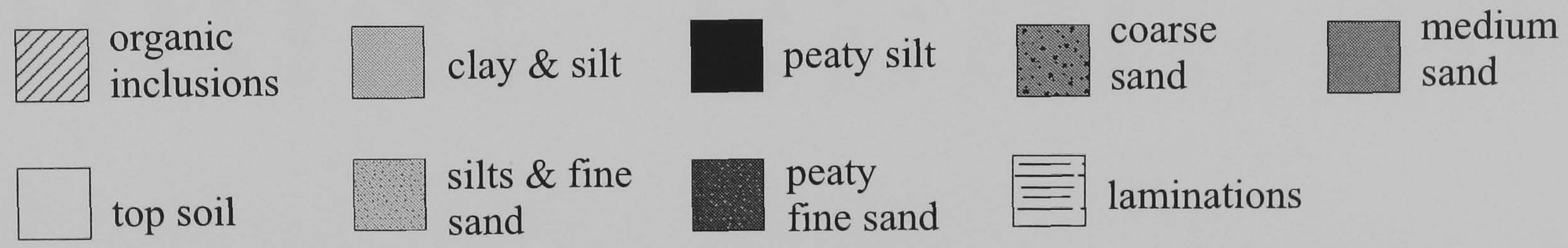






Dovecote Floodplain Transect 1

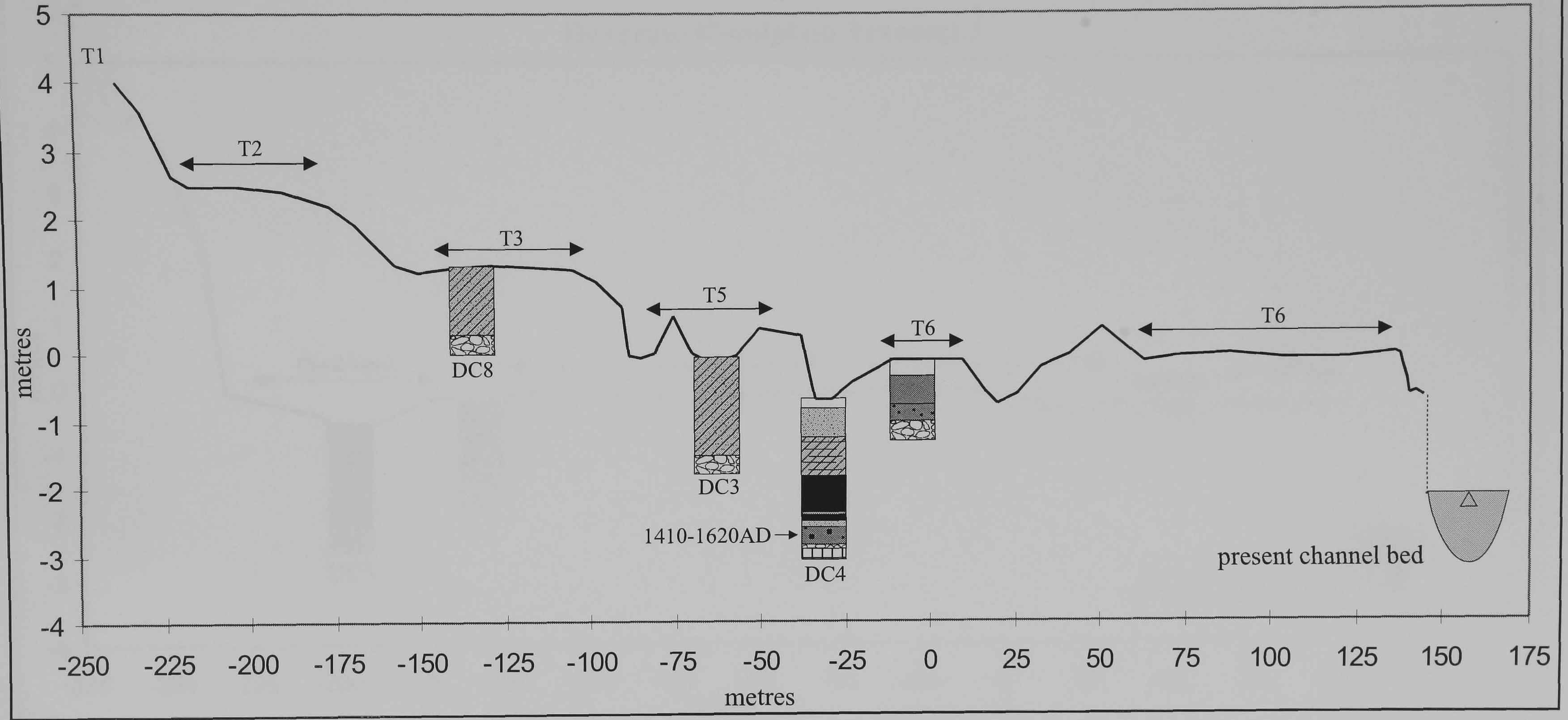


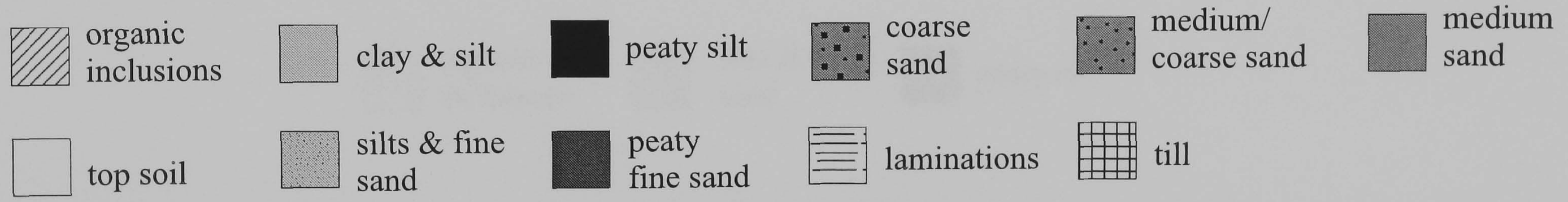


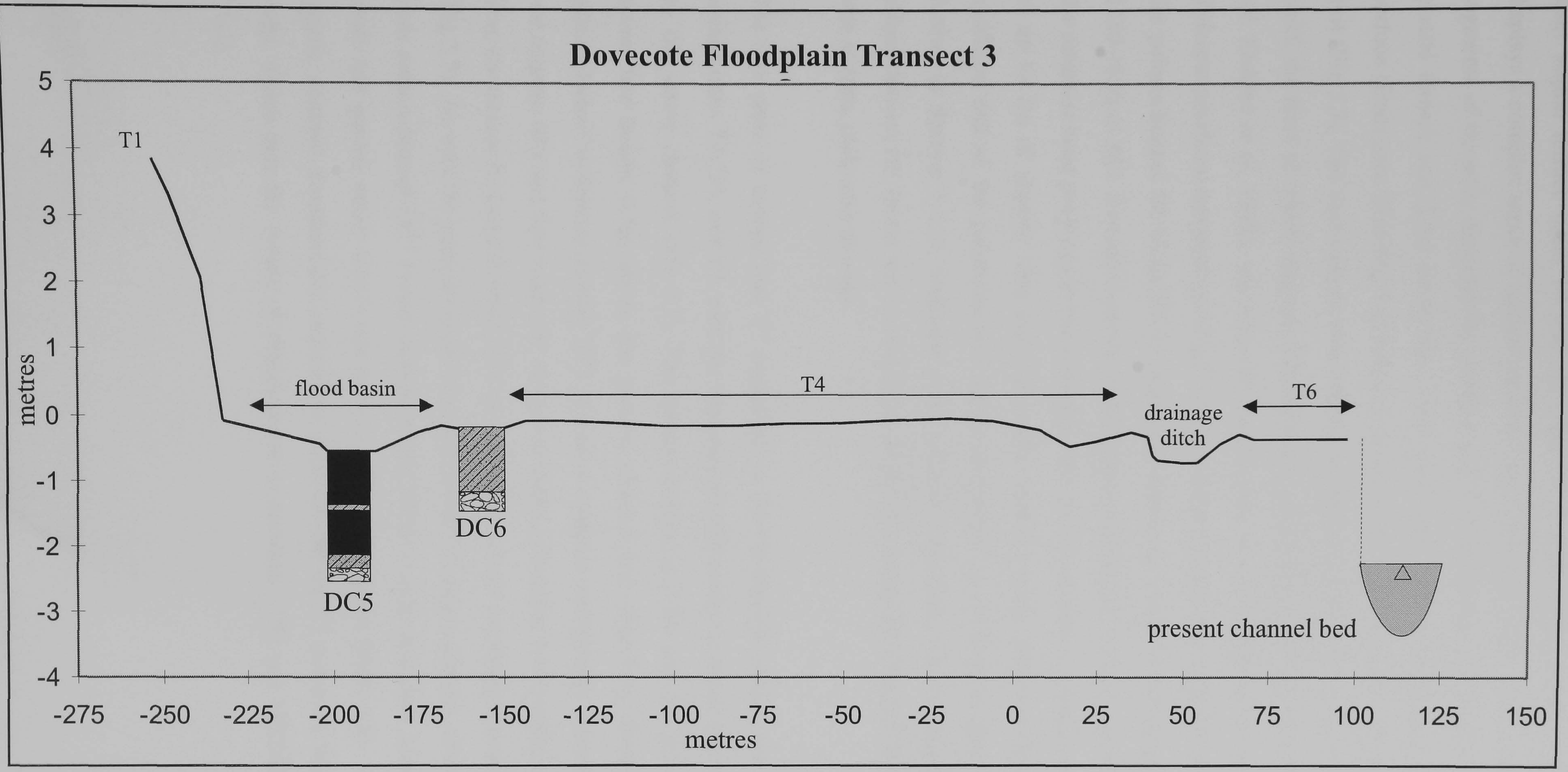
T4 Two extensive remnants of terrace unit T4 are preserved on the Holocene valley floor (Fig 5.1) and have been correlated by terrace surface height measurements. The unit lies c.4m below the putative late glacial terrace, and 3m above the active river bed (Fig 5.3 and 5.5). A palaeochannel developed on the upstream section has a near straight planform morphology that follows the line of the terrace bluff from T2. Here the terrace has been laterally eroded by younger channels, including that associated with T7. Detailed coring of the palaeochannel has revealed a channel fill that comprises 1.5m of fine sands, silts, and clays with peaty deposits (core DC2; Fig 5.3) whereas the adjacent terrace sediments are characterised by a thin top soil and c.0.5m of alluvial sands above coarse sands and gravels (Fig 5.11). The larger downstream section of T4 extends 200m laterally from the putative late glacial terrace to the lower terrace units T5 and T6. The terrace surface morphology reveals sinuous palaeochannel forms, and a former flood basin which lies adjacent to the steep bluff of T1 (Fig 5.5). The flood basin contains up to 2m of fibrous silty peats (core DC5; Fig 5.5), the gravel base of which reveals a 6m drop in gravel surface height from T1 to T4, although the flood basin was found to be deeper than the T4 palaeochannel therefore calculations of the difference in gravel surface heights between the two units can vary by up to 0.5m. The radiocarbon date obtained from bulk organic sediments from the bottom 10cm of the palaeochannel fills of DC2 (Fig 5.3) dated the timing of channel abandonment to before 2440-1920cal BC; in the late Neolithic or early Bronze Age.

T5 Two fragments of terrace unit T5, lying 2.6m above the active channel bed, are preserved at the Dovecote site with the upstream part of the reach exhibiting a palaeochannel running along the edge of the terrace bluff (Fig 5.1). Part of T5 has been degraded by the construction of a farm track. The downstream section of the unit is partially obscured by a 20th century conifer plantation. Sediment core DC3 (Fig 5.4), extracted from the palaeochannel along the upstream section of the unit revealed a complex stratigraphy of peaty and clayey silts to a depth of 1.5m. The palaeochannel gravel bed is at an equivalent height to T4 although slightly higher than the younger unit T6. This terrace lacks direct dating control but, based on its location and terrace heights the timing of channel abandonment and terrace aggradation can be dated to between 2440-1920cal.BC and 1410-1620cal.AD (the post abandonment date for T6), thus bracketing it as mid-late Holocene (Fig 5.6).

Dovecote Floodplain Transect 2






Dovecote Floodplain Transect 3
5
4
3
2
1
0
-1
-2
-3
-4
metres
T1
flood basin
T4
drainage ditch
T6
DC6
DC5
present channel bed
-275
-250
-225
-200
-175
-150
-125
-100
-75
-50
-25
0
25
50
75
100
125
150
metres
organic inclusions
silts & fine sand
peaty silt

T6 Inset within terrace units T4 and T5, unit T6 is a laterally extensive terrace that displays a complex array of surface palaeochannel forms (Fig 5.1). There are two main segments of the unit, dissected by younger unit T7. The terrace lies 4m below the late glacial terrace and 2.3m above the active river bed, with the palaeochannel gravel surface (from core DC4-Fig 5.4) being at an equivalent height to that of the lower T7 unit (Fig 5.3). The upstream section exhibits a palaeochannel running along the terrace bluff, the form of which suggests abandonment *via* chute cut-off and channel avulsion (cf. Erskine *et al.* 1992), whereby the channel cuts across the terrace unit to create a different planform morphology (Fig 5.1). A radiocarbon date from 180-190cm depth of the palaeochannel fill (from DC4) places the timing of chute cut off shortly prior to 1410-1620cal AD. Extensive coring of the palaeochannel and terrace sediments (along the meander bend proximal to the sediment core DC4) revealed a complex stratigraphy of up to 2m of organic silts and fine sands, with a coarse sediment deposit at the upstream end of the palaeochannel reach, interpreted as an alluvial plug (discussed further in Section 5.3.2). Sediment cores extracted from the deepest sections of the palaeochannel fill found only a thin layer of gravels lining the channel, below which was a clean, pink, clay deposit.

T7 The two parts of terrace unit T7 preserved on the floodplain surface are set within terrace units T4, T5, and T6, with the upstream section presently being laterally eroded by the active channel (Fig 5.1). The terrace surface is 2.5m and the palaeochannel gravel bed height 0.5m above the present channel bed (Fig 5.3). Detailed coring palaeochannel sediments around DC7 reveals a complex stratigraphy containing peaty and organic silts and fine sand over the gravel surface (Section 5.4.2) while cores taken from the terrace revealed 0.5m of alluvial sands and top soil overlying coarse sediments (Fig 5.3). As with the palaeochannel associated with T6, deep sediment cores extracted from palaeochannel DC7 found sections of the fill to overlie less than 2cm of coarse sands and gravel, under which was found a pink clay deposit (Plate 5.6). The former regime, channel abandonment and terrace development for T7 is known from historic maps, which date the timing of abandonment to between 1770 and 1822AD (Section 5.1.1).

Dovecote Terrace Sequence

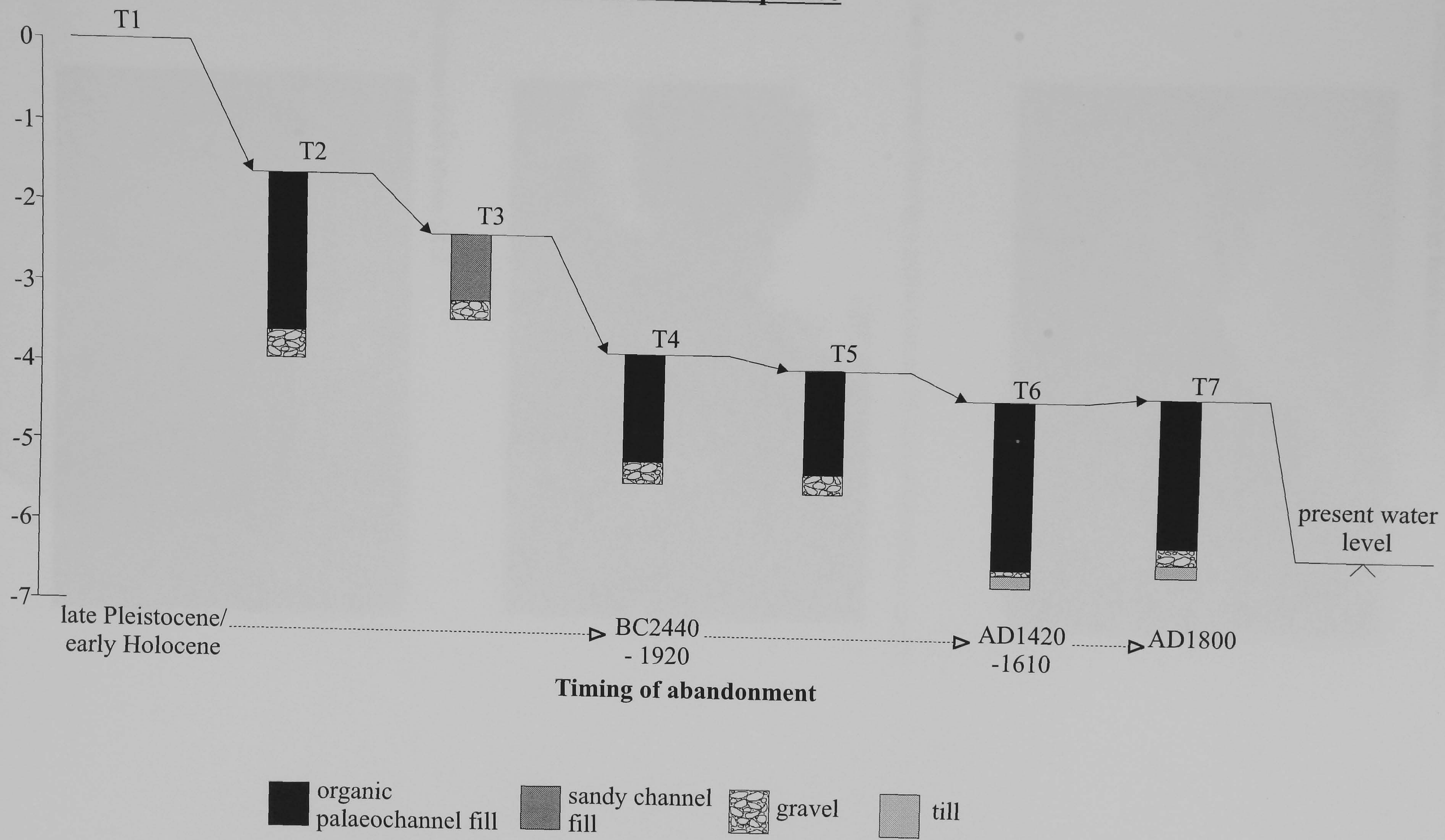


Plate 5.1 Dovecote composite river bank sediments

Plate 5.2 Bank exposure showing a palaeochannel fill inset within glacial gravels

Plate 5.3 The terrace bluff above DC2

Table 5.2 Sediment log of an exposed bank section (Plate 5.1)

Depth (cm)	Description
0-80	fine overbank sediment, fine sand and silty fine sand and top soil
80-150	massive imbricated sandy gravel, some sandy lenses
150	water level

Interpretation of Dovecote valley floor terraces and palaeochannels

Rapid incision at the end of the glaciation following isostatic uplift and rapid adjustment to changing fluvial regimes has resulted in the presence of high late glacial-early Holocene coarse sand and gravel terrace units in many British upland catchments (Harvey 1985, Tipping 1995, Moores *et al.* 1999, Macklin 1999, Passmore & Macklin 2000). Similarly, the morphology of terrace unit T1 at Dovecote indicates fluvial incision and reworking throughout the Holocene. Height differences between terraces T1, T2 and T3, and the younger T4-T7 terrace unit height differences (Fig 5.6), signify a net incision into the valley floor of up to 4m prior to the alluviation of T4. Conversely, from *c.* 2440-1920cal.BC (the post-abandonment date for palaeochannel DC2, associated with T4) there is little difference in terrace surface heights indicating a limit to net fluvial incision. Valley floor construction from the early to mid Holocene was therefore characterised by fluvial incision into glacio-fluvial gravels, creating step like fluvial terrace units.

The surface form of terrace unit T4 exhibits a number of palaeochannels of varying sinuosity (Fig 5.1) suggesting two potential interpretations of former channel planform geometry. Firstly the channel forms may be representative of a former multi channel reach (cf. Brown 1997b. Alternatively, they may reflect a series of single thread meandering active channels. The extensive reaches of palaeochannel associated with terrace units T6 and T7 reveal a similar sinuous single thread channel planform to the contemporary channel. The general channel planform morphology of palaeochannels associated with terraces post dating the limit to fluvial incision, is that of an upland meandering river (Lewin 1992).

The period between the alluviation of T4 and abandonment of DC4 (with alluviation of T6) spans over 3000 years. The limited preservation of terraces T4 and T5, constructed during the past 3000 years, infers some lateral reworking of the floodplain prior to 1410-1620cal AD. The spatial extent of both T6 and T7 however implies limited lateral floodplain reworking over the past 500 years with the morphology of the palaeochannels suggesting the river to

have been prone to avulsion and meander cut-offs. The change in floodplain construction over the recent historic period, with extensive lateral channel abandonment occurring, indicates a change in either fluvial process or intrinsic physical conditions. As seen from the sediment coring, the former river channels associated with T6 and T7, at the deepest points only a thin veneer of coarse sediment was present at the base, beneath which was clay (Plate 5.6). The clays are not depicted in the geological drift map of the area (Fig 3.4), and hence the properties, spatial extent and depth are unknown. It is assumed, however, that reaching the lower limit of the glacio-fluvial coarse sediments and entering clay deposits, even if localised, may have affected patterns of floodplain construction (Brewer & Lewin 1997).

With respect to floodplain sedimentology, a similarity exists between the palaeochannel sedimentary sequences of the fills of DC1, DC2 and DC3, associated with terraces T2, T4 and T5 respectively (Fig 5.3 and 5.4). Cores extracted from the palaeochannels reveal fining upward sequences, the preservation of organic or peaty material above the basal sediments, and the presence of laminated fine silts and clays in the upper sections of the fills. Each fill therefore depicts the progressive reduction in fluvial inputs following abandonment (Erskine *et al.* 1992), the establishment of vegetation cover, in and around the former channels, and continuous sedimentation of suspended fines during overbank flows (Asselman & Middelkoop 1995, Marriott 1998). The upper parts of the fills are characterised by mottled organic material signifying the oxidisation of formerly waterlogged material *via* aerobic conditions. Conversely both the sedimentary characteristics of the total flood basin fill associated with T4 (DC5) and the upper part of the fill of palaeochannel DC7 associated with T7, contain peaty silts and fine sands with little evidence of fluvial inundation. The continuous waterlogged status of both results from the low permeability and high porosity and, for DC7, the proximity of the active channel (Fig 5.1).

5.1.1 Channel changes since the 18th Century

The overall trend of changes in channel morphology along the Dovecote reach from 1771 to 1822 is a reduction in sinuosity associated with major meander cut-offs (Fig 5.7A). The parish boundary shown on the 1822 map follows the upper limit of the former meander bends and indicates the magnitude of change along the reach. One section of a former channel (associated with terrace T7) remains connected to the main channel at the downstream end following abandonment (Fig 5.7A). In addition, two mid channel bars upstream of the Dovecote reach are evident on the 1771 map, but no morphological expression of these

Figure 5.7

Dovecote Site: Historic Channel Change 1771-1822 & 1822-1840

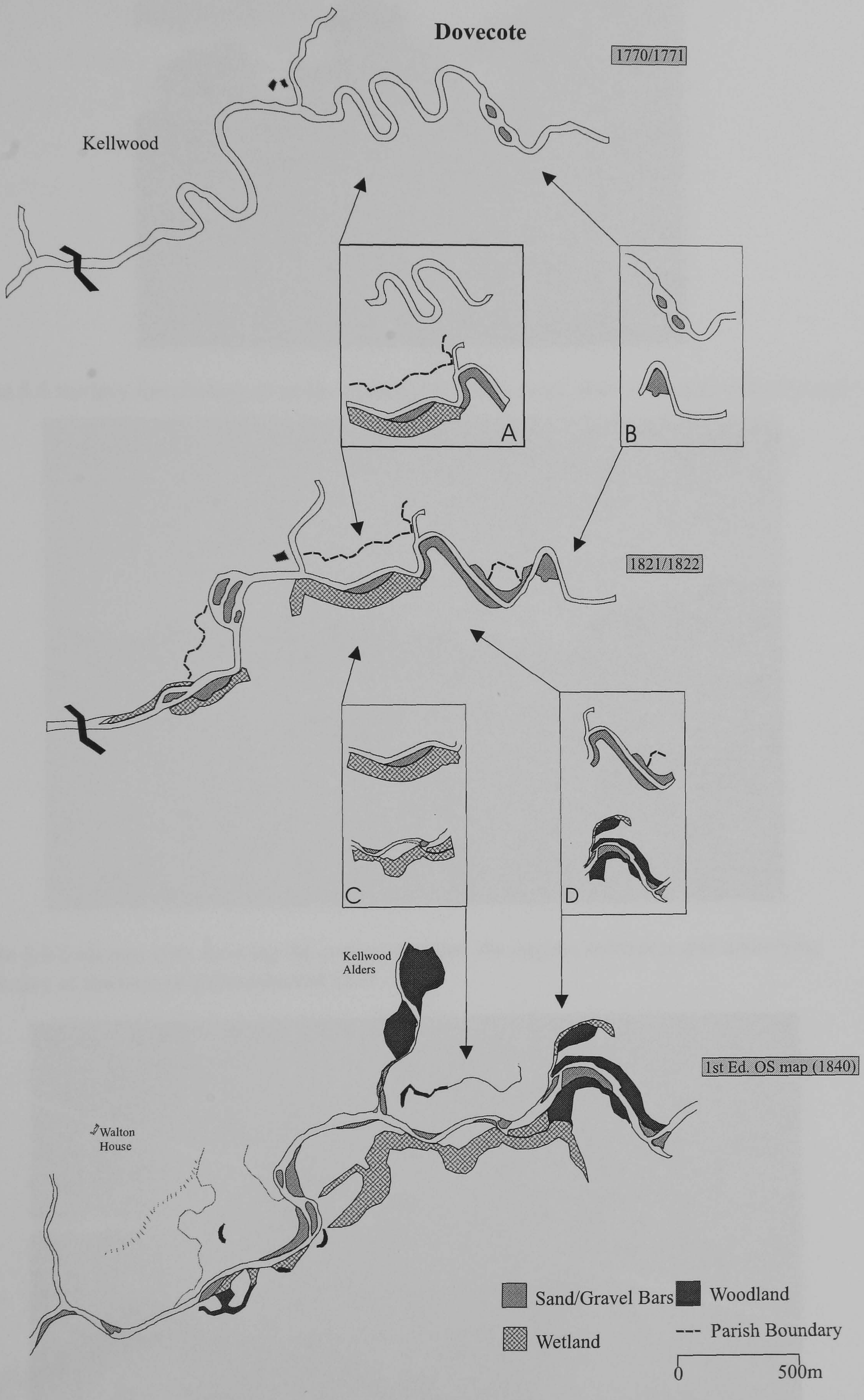


Plate 5.4 DC4 surface morphological evidence for the former river channel

Plate 5.5 Surface morphology of palaeochannel DC7 with small alder woodland at the far end

Plate 5.6 Sediment core showing the contact between the organic sediments and underlying pink clay at the base of palaeochannel DC7

features can been seen from the 1822 map (Fig 5.7B), indicating the erosion and transportation of these sediments or their incorporation into the floodplain.

From the historical maps it is evident that significant lateral channel change occurred in the period between 1771 and 1822. Reasons for the severity of change are discussed in Chapter 7. The morphological expression of the meander cut-off can be seen on the contemporary floodplain surface and is associated with terrace unit T7 (Fig 5.1).

Assessment of channel change along the same reach reveals that between 1822 and 1840 the River Irthing has experienced the deposition of two point bars at its upstream limit (Fig 5.7C). At the location of the upstream meander cut off (Fig 5.7D) an increase in the meander radius has occurred alongside the development of a point bar on the inside of the meander bend and a depositional bar at the mouth of the backwater of the abandoned channel. A wetland has also developed along the former river channel (Fig 5.7D).

There is a distinct change in the magnitude and characteristics of channel modification between the 1771-1822 period and the 1821-1840 period, although it is acknowledged that the period of time between map survey dates is only 19 years, whereas the period between the first two maps is 51 years. At Dovecote, the period between 1821 and 1840 was dominated by the development of a number of fluvial bars. The bar at the mouth of the channel abandoned during the 1771-1822 period suggests the development an alluvial plug which will have reduced the fluvial inputs into the palaeochannel and enabled the development of a wetland habitat. Slight changes to channel planform, with the increase in meander radius (Fig 5.7D) infer some lateral reworking of floodplain sediments.

More recent maps of the River Irthing indicate an overall rationalisation of the channel between 1840 and 1972 (Fig 5.8). Between 1840 and c.1930 the major trend in channel change is a slight widening of the active channel with the presence of lateral, point and mid-channel bars suggesting an increase in coarse sediment supply to the system. By the 1970s, the channel belt has narrowed and rationalised around the bars forms, resulting in an increase in sinuosity (Fig 5.8). The overall increase in sinuosity from 1840 to 1972 is from 1.442 to 1.674, indicating a degree of lateral floodplain reworking. Bank material along the Dovecote reach, as described in the exposed bank section, comprises unconsolidated sandy gravels (cf. Brewer & Lewin 1998). The bank material therefore will be prone to lateral erosion during high flows, as seen during a high discharge event in 1998 (Plate 3.2).

5.2 Results and Analysis for Palaeochannel DC2

DC2, associated with terrace T4 (Fig 5.1) is a relatively straight palaeochannel reach, with a sinuosity of 1.08, which follows the line of the terrace bluff of T4 (Plate 5.3). A 100m section of the palaeochannel was selected for detailed sedimentological and plant macrofossil analysis. Radiocarbon dates obtained from basal organic sediments indicate that palaeochannel infilling began at 2440-1920cal BC (Table 5.1).

5.2.1 Palaeochannel geometry

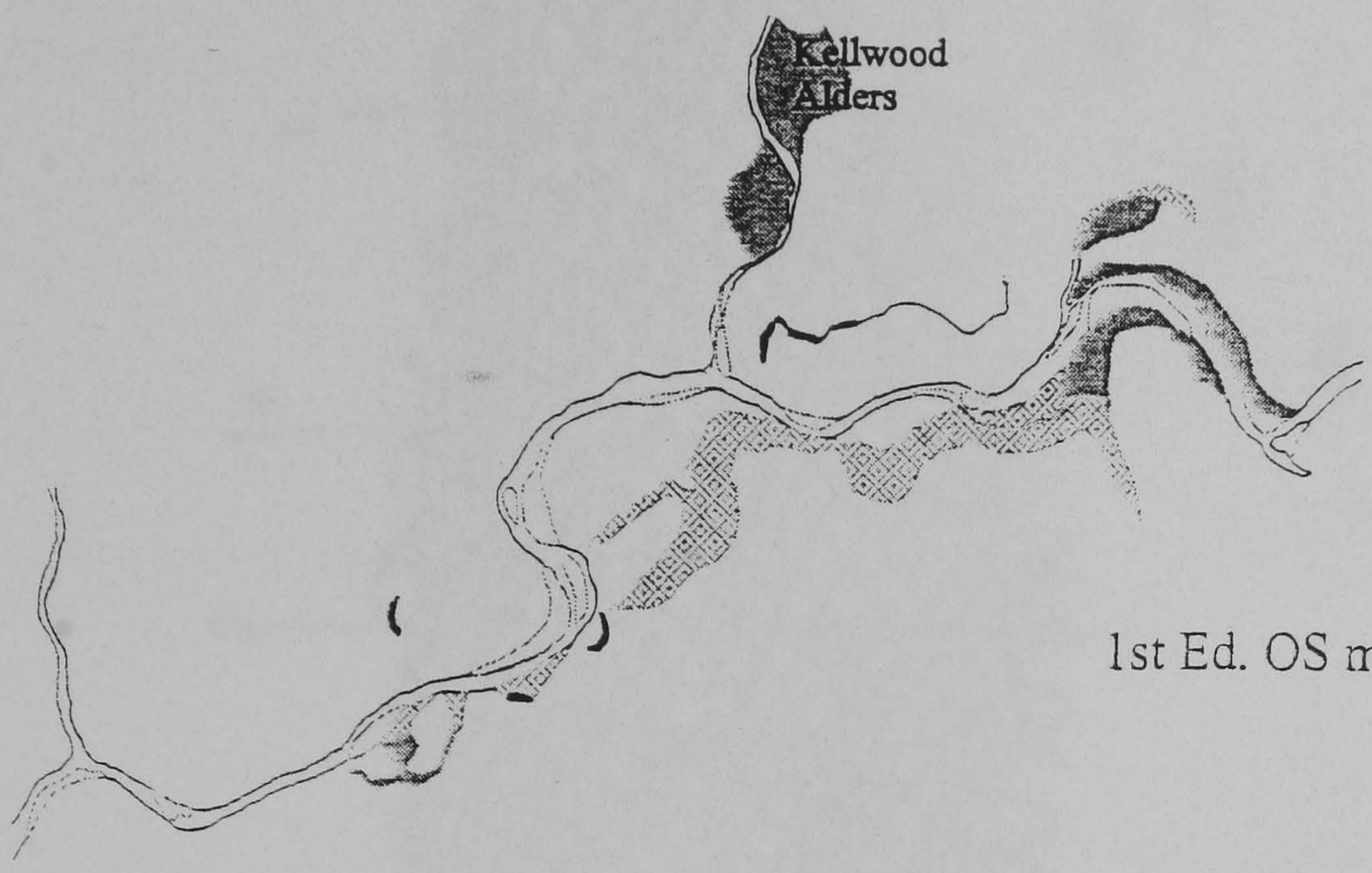
Nine transects along palaeochannel DC2 were cored at 2m intervals and at higher resolutions to ascertain change of slope where necessary. Each core location was surveyed (Fig 5.10). From the cores extracted along transects 1 to 5, sediments were logged. From the cores taken along transects 1a to 4a, depth of palaeochannel fill was recorded.

Reconstruction of the former river gravel bed shows a variable channel morphology with well defined right bank channel sides and poorly defined left bank channel sides is evident (Fig 5.9). Compared with the contemporary channel and palaeochannels DC4 (with terrace T6-Fig 5.16) and DC7 (with terrace T7-Fig 5.22) at the Dovecote site, DC2 is relatively shallow and narrow. Transects 1, 4, 4a and 5 (5.10) show an almost symmetrical channel, with a square cross section, and steep channel sides, whereas the left banks of transects 1a and 2 drop in elevation from the centre of the gravel bed surface. A distinct elevation in the channel bed morphology, 0.8m wide and 1m high, is evident within the transect 3a cross section. Upstream, in the gravel surface of transect 2a, can be seen a drop in bed elevation and the presence of a depression, 5m wide and c.0.6m deep (Fig 5.10).

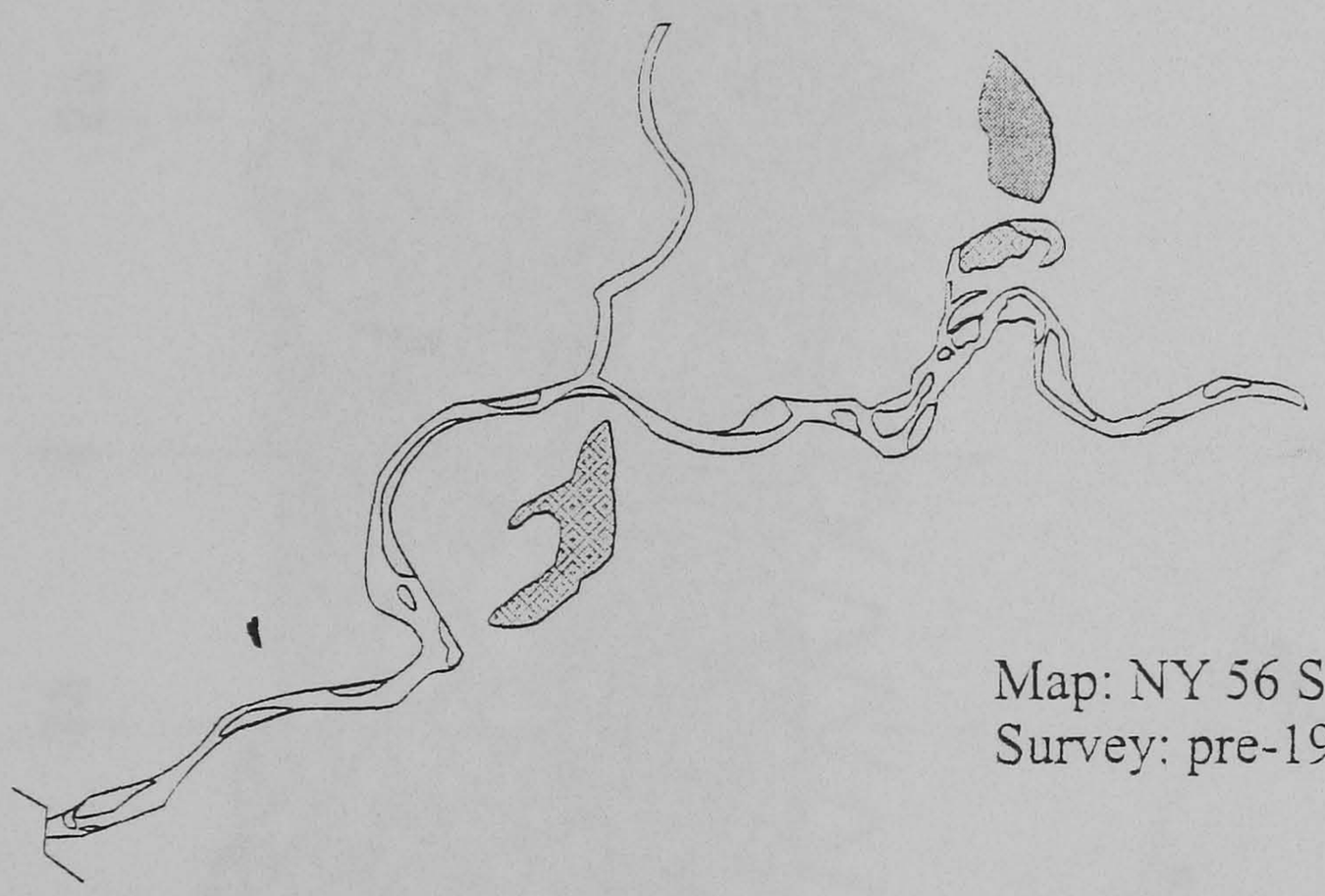
Although it is difficult to ascertain the nature of channel abandonment from the geomorphology of palaeochannel DC2 due to the limited length of channel preserved, the reconstruction suggests a relatively straight local channel morphology. The section of the reach where there is no evidence for a left bank to the channel is interpreted as the confluence point with another former arm of the channel. The reach of DC2 may thus have been one part of a multi channel reach or locally subject to avulsion prior to wholesale abandonment. The lower channel capacity of the reach, as suggested by the channel cross sections indicates that the channel may have been part of a locally wider active channel belt. Comparison of these planform characteristics with the downstream section of terrace unit T4

Recent Channel Change along the River Irthing

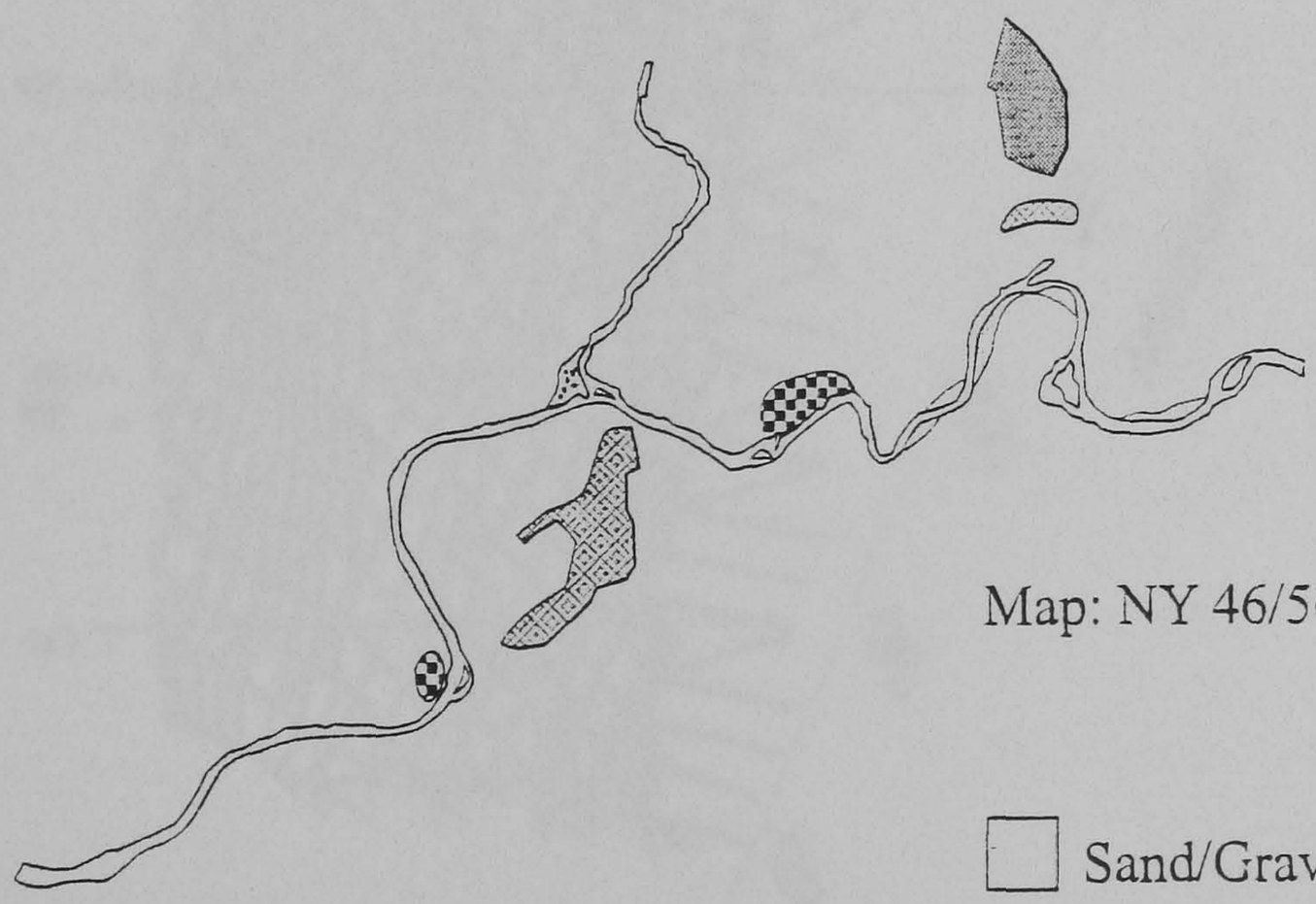
Figure 5.8



1st Ed. OS map (1840)



Map: NY 56 SW (1952)
Survey: pre-1930



Map: NY 46/56 (1972-74)

Sand/Gravel Bars

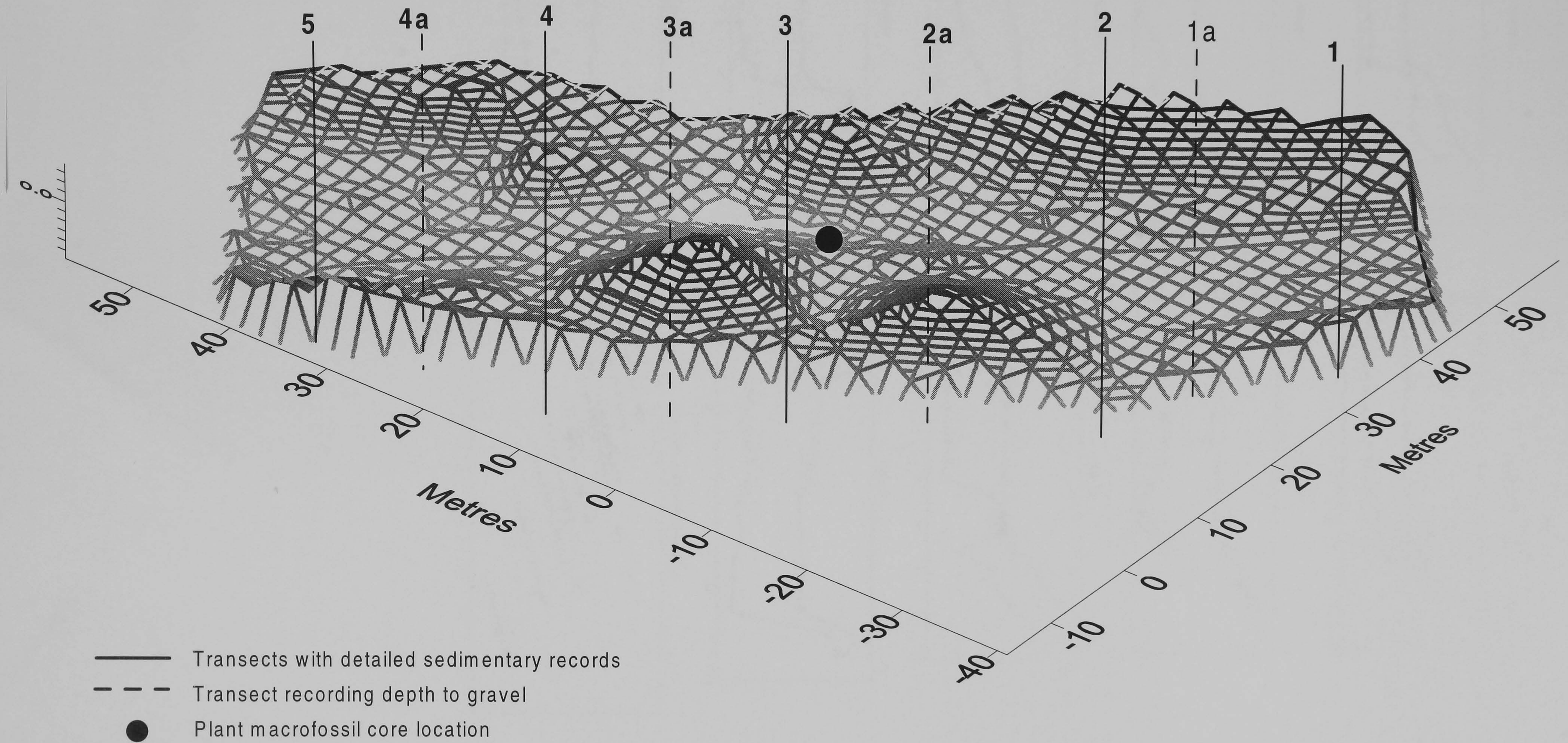
Wetland

Woodland

Gravel Extraction

Figure 5.9

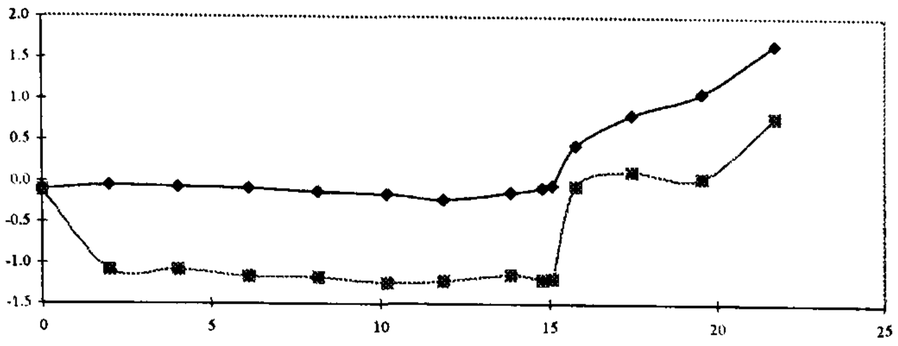
Dovecote Palaeochannel 2 (DC2) Gravel Surface Morphology



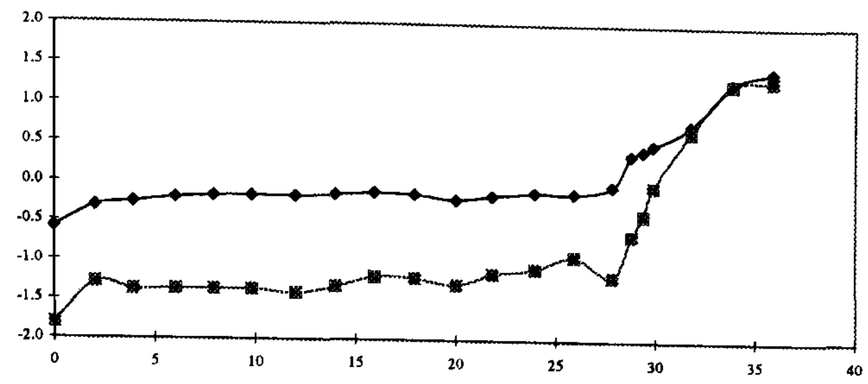
Dovecote Palaeochannel 2 (DC2) Gravel Surface Cross Sections

Figure 5.10

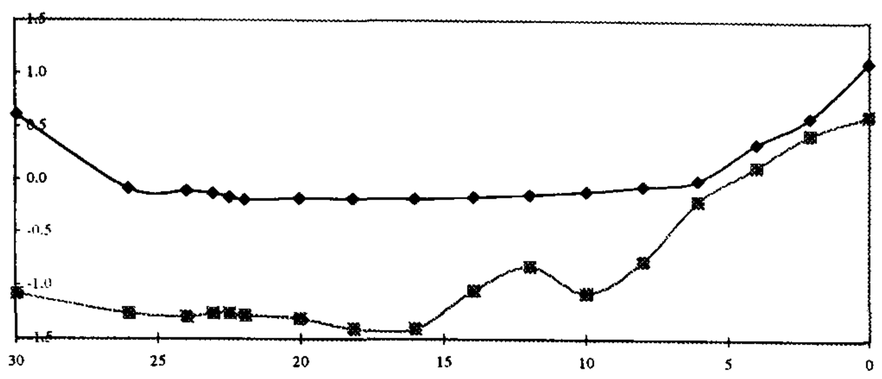
Transect 1



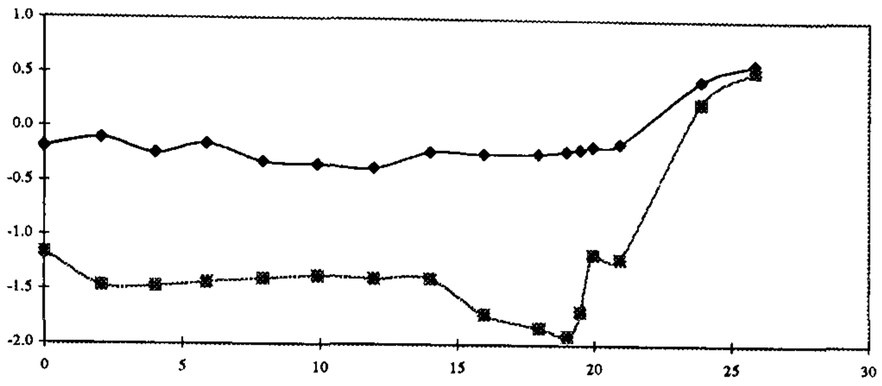
Transect 1a



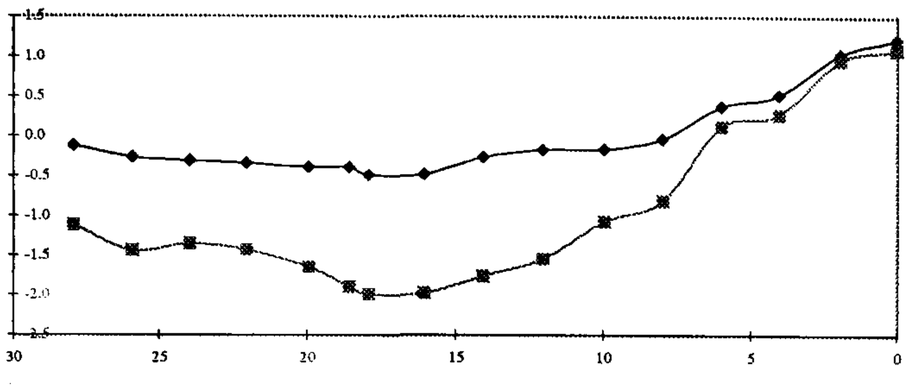
Transect 2



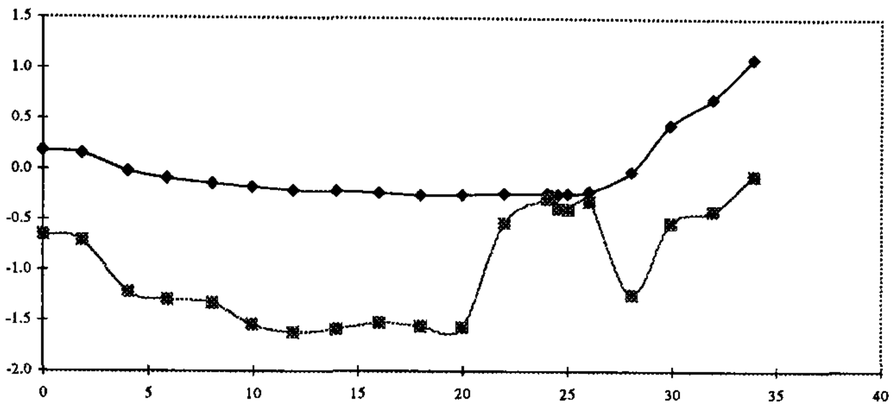
Transect 2a



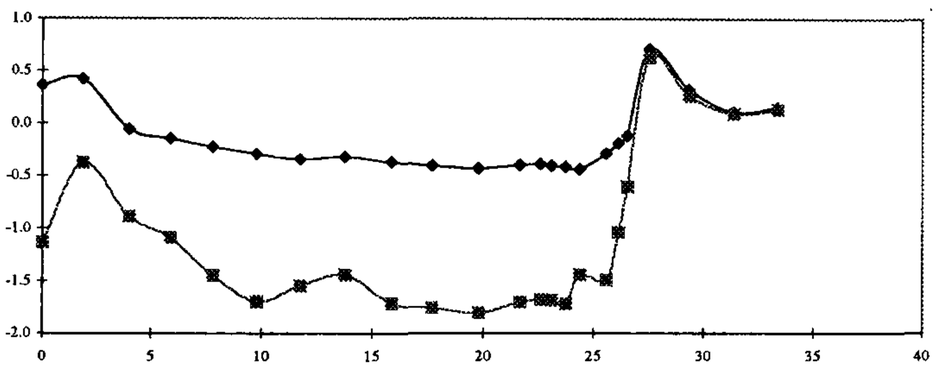
Transect 3



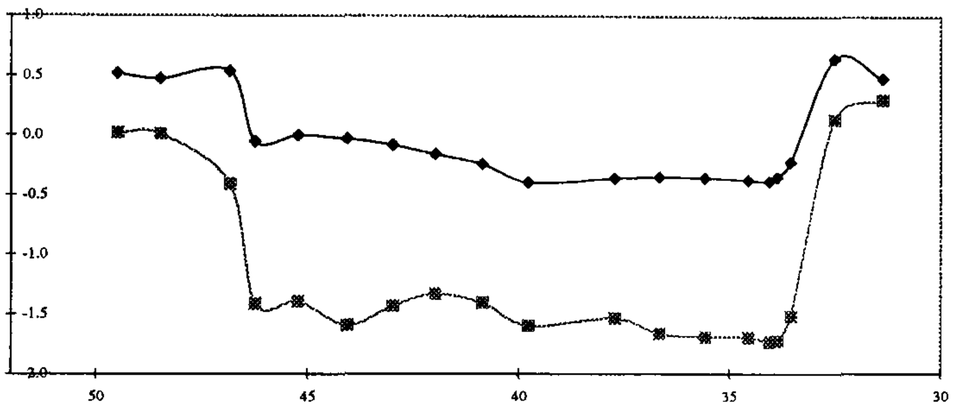
Transect 3a



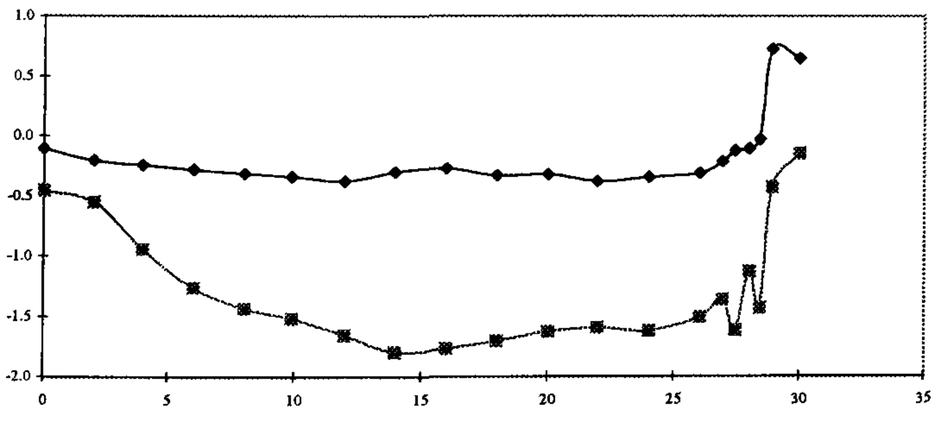
Transect 4



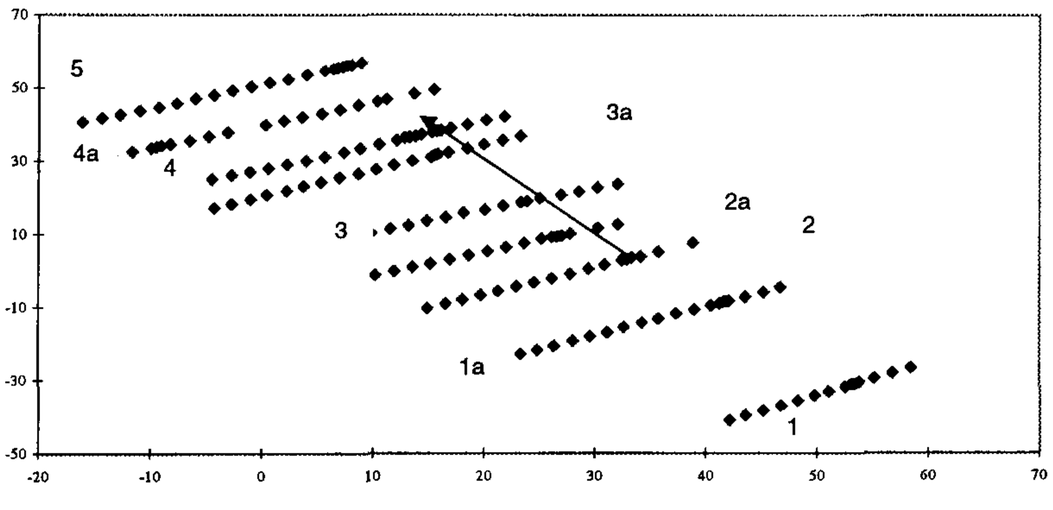
Transect 4a



Transect 5



Dovecote Palaeochannel 2 (DC2) Core Locations



where sinuous channel forms are exhibited (Fig 5.1) indicates the local characteristics of planform morphology. At a smaller spatial scale, bedforms of the former channel can be seen from the surface morphology of transect 3 which is interpreted as a former lateral bar (Fig 5.10-transect 3). Immediately upstream of the bar, the depression evident in transect 2a (Fig 5.10) suggests localised scour.

5.2.2 Lithostratigraphy of channel fills in palaeochannel DC2

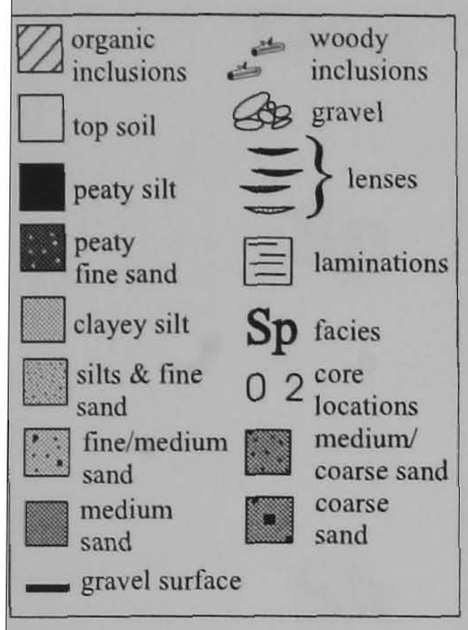
Figure 5.11 shows the results of the sediment logs taken along five of the nine transects across DC2, with transect 1 situated at the upstream end of the reach and transect 5 furthermost downstream. Using the lithofacies classification (Table 4.2) the infill sediments have been divided into facies representing specific depositional environments. Each facies is described and discussed below whilst a model of the temporal sequence of the facies is shown in Fig 5.12.

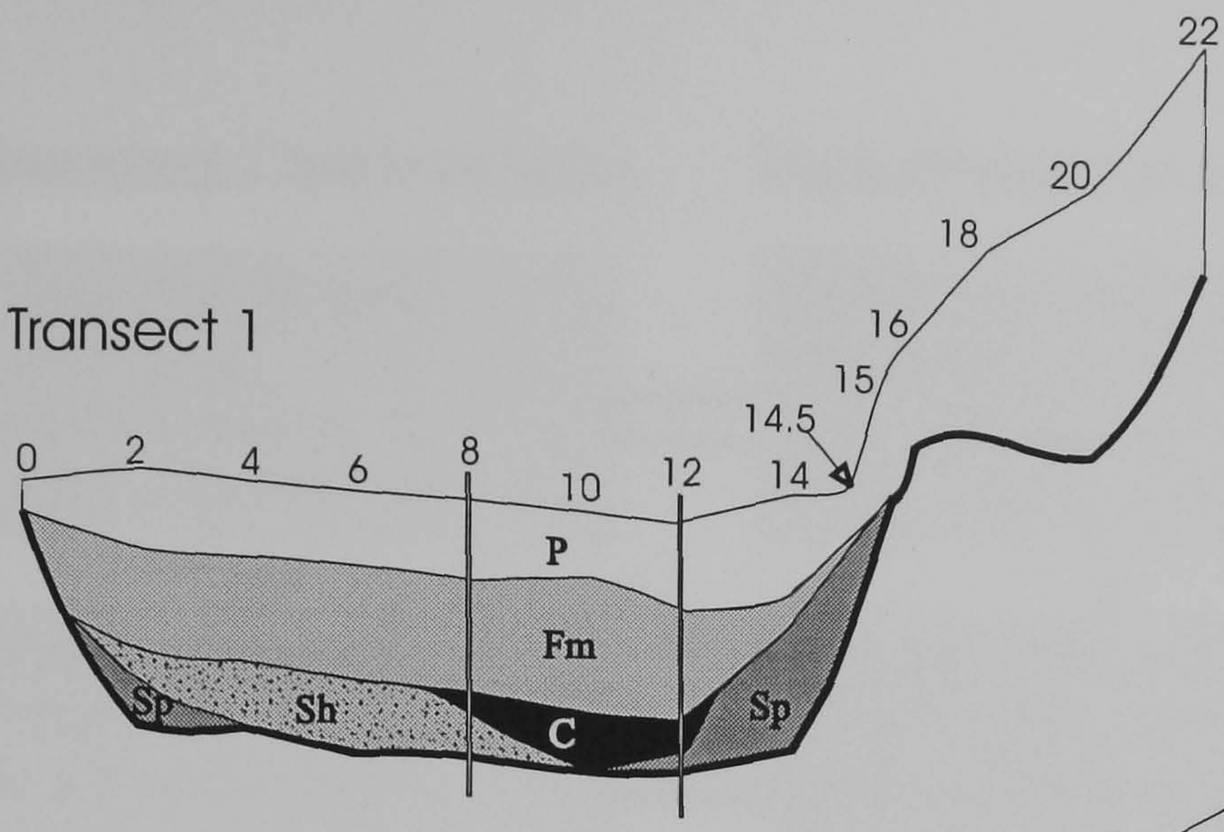
Coarse sand deposits overlie the gravel surface of transects 4 and 5, while medium and medium coarse sands form the lowest channel fill sediments in transects 1 and 3 (Fig 5.11) which began infilling *circa* 2440-1920cal.BC. These have mostly been deposited on the left channel side, with the exception of transect 1 where medium sands line the sides of the former channel bed. The sediments form a coarse to medium sand facies, Sp, which lines the gravel surface at the sides of palaeochannel DC2 and is significantly coarser than the overlying sediments. The facies are interpreted as lateral accretion deposits, formed when the channel was active. Lateral deposits are known to lie over channel bars, a lateral bar in the case of DC2 (Bridge 1985, Jones 1999). Transect 5 shows the sediments to locally infill shallow depressions in the underlying gravel surface. The different grain sizes and sedimentation patterns of the sediments which line the gravel surface and form facies Sp may reflect the variability of flow velocities and sedimentation rates through the reach when it was part of the active channel.

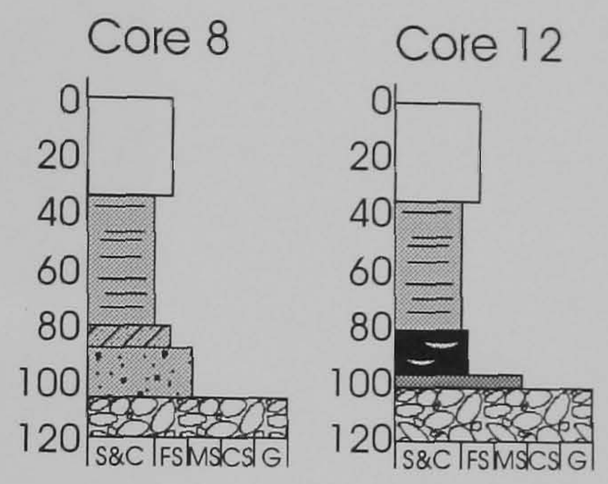
Within the centre of transects 1, 2, 3 and 4 and overlying the Sp facies of transects 5 are fine to medium sands (Fig 5.11). The sediments are up to 60cm deep (Core 22-Transect 4). These laterally extensive sediments form a medium/fine sand facies Sh (Fig 5.12). The finer grain size and reduced spatial variability of sediment texture, by comparison with the underlying sediments, is interpreted as the result of lower energy flow or reduced sediment supply. The sediments were deposited therefore either following channel abandonment or during reduced flow conditions following channel rationalisation (Fig 5.12). Sediment from this facies contained organic material within a number of cores (e.g. Core 14-Transect 4, Core 12-

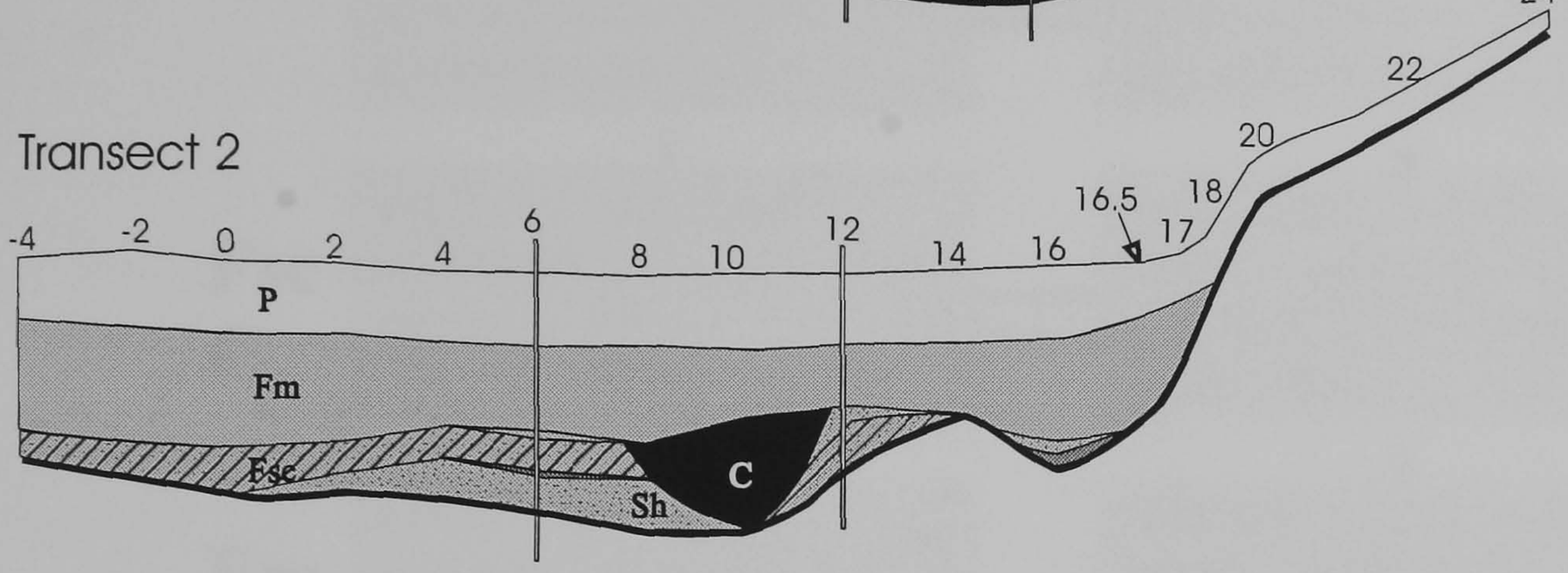
Figure 5.11

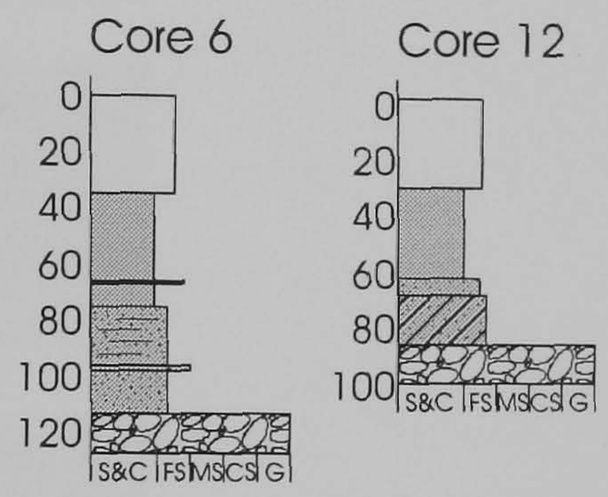
Dovecote Palaeochannel 2 (DC2) Sedimentary Infills

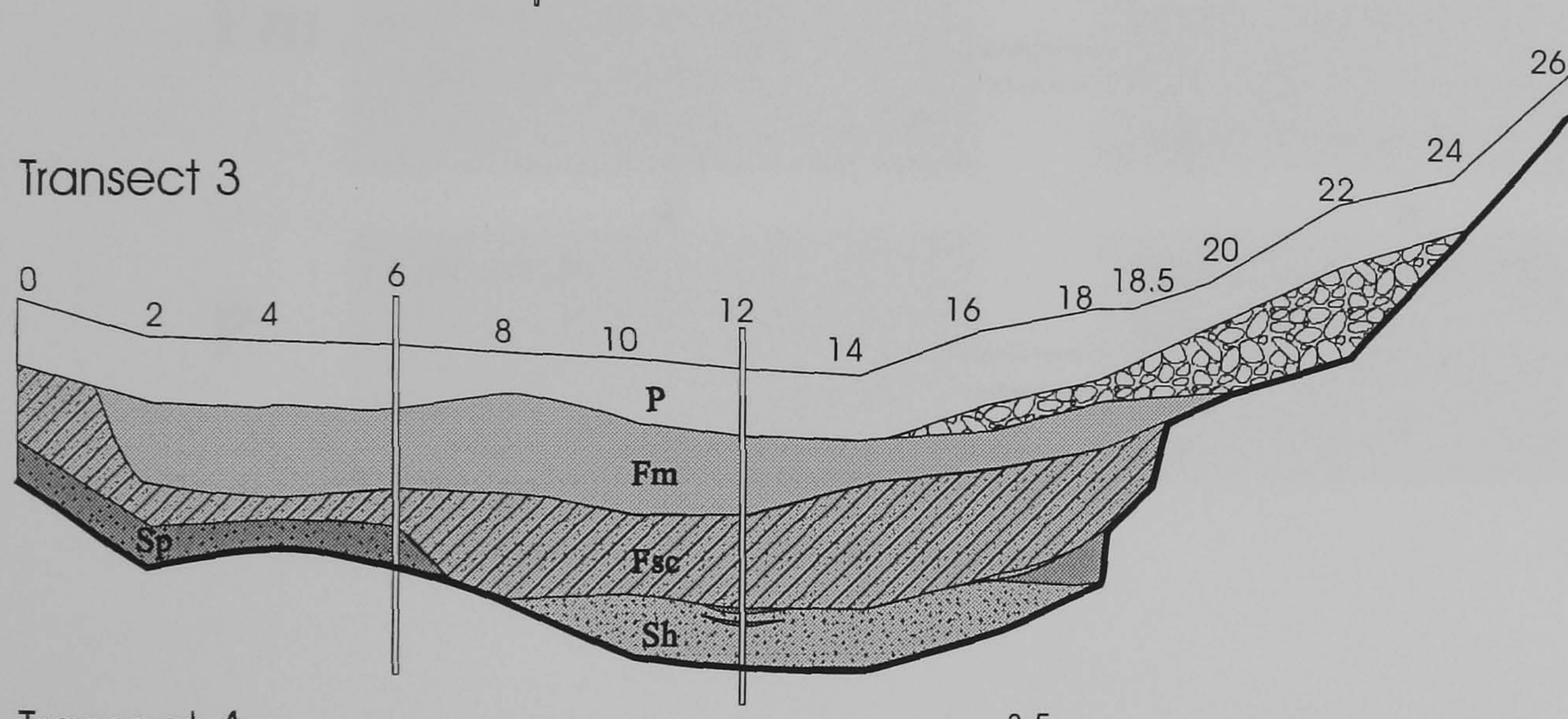


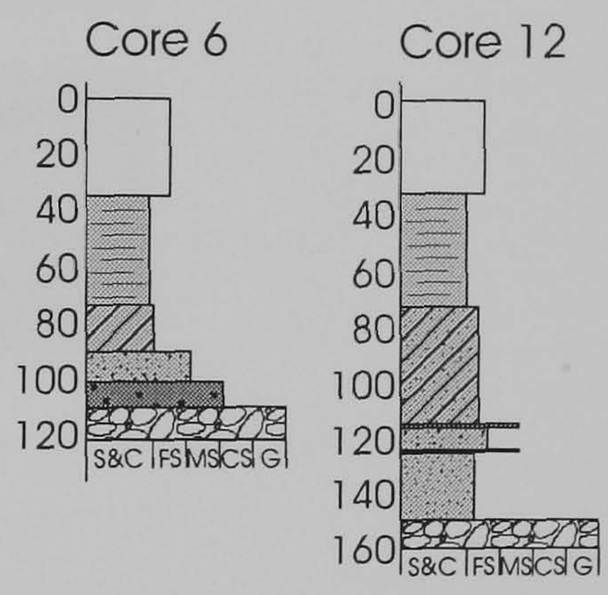


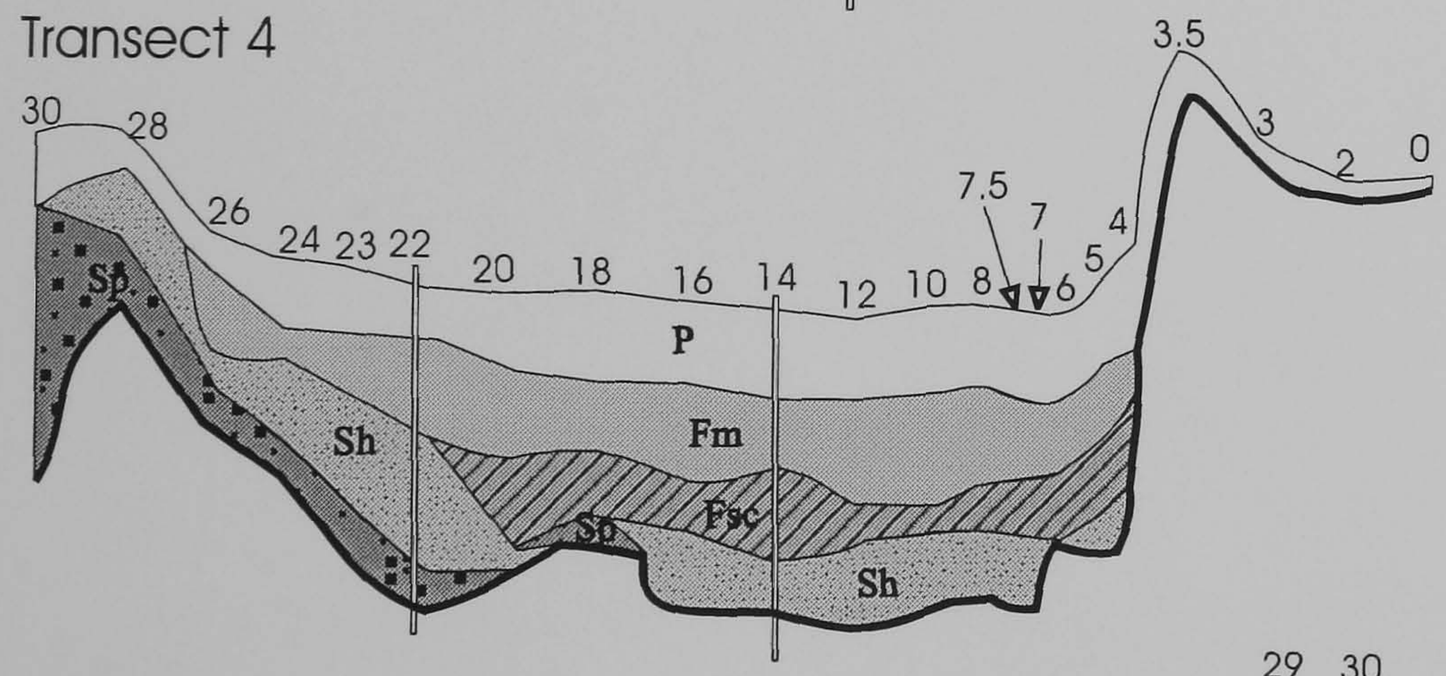


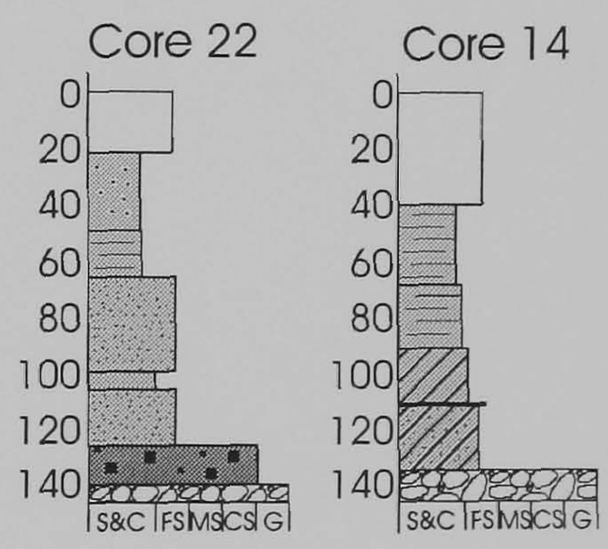


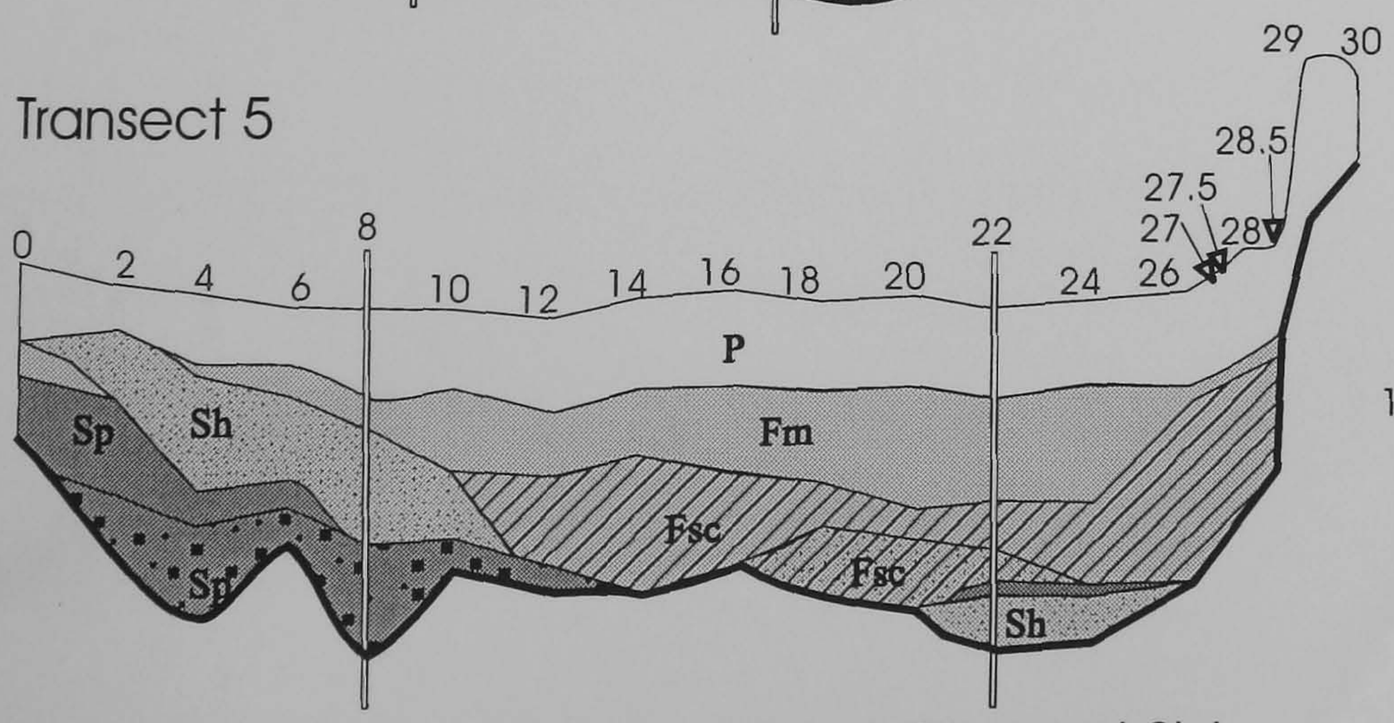


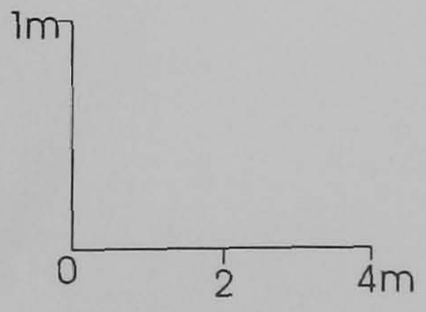


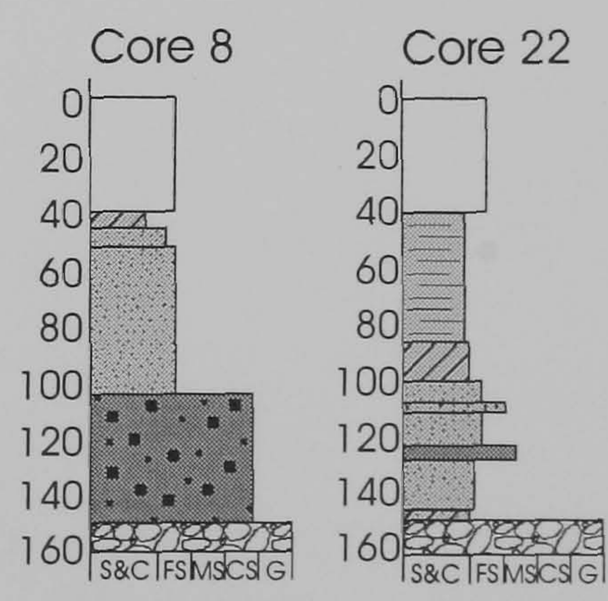






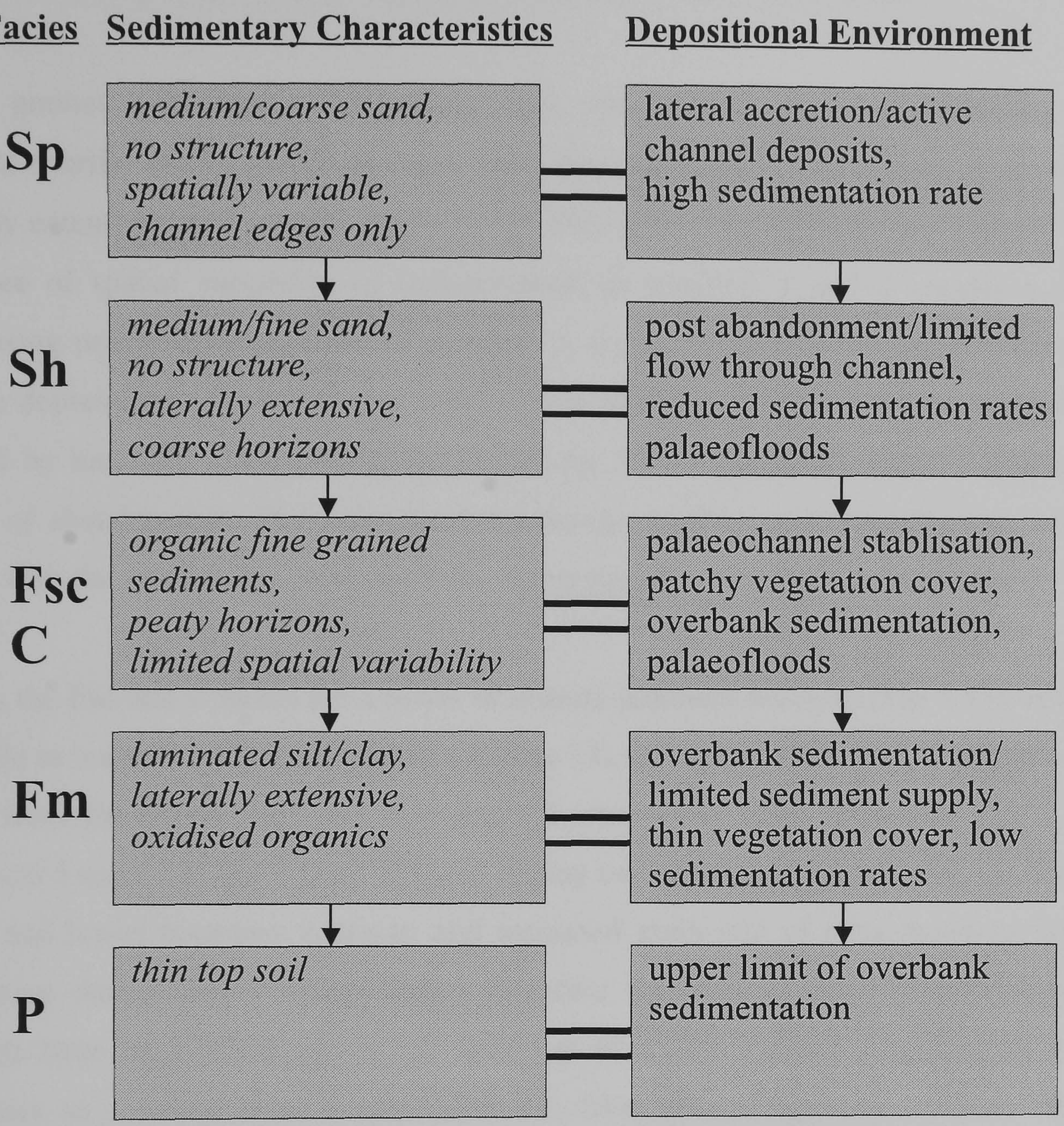






DC2 - Model of Sedimentary Deposition

Figure 5.12



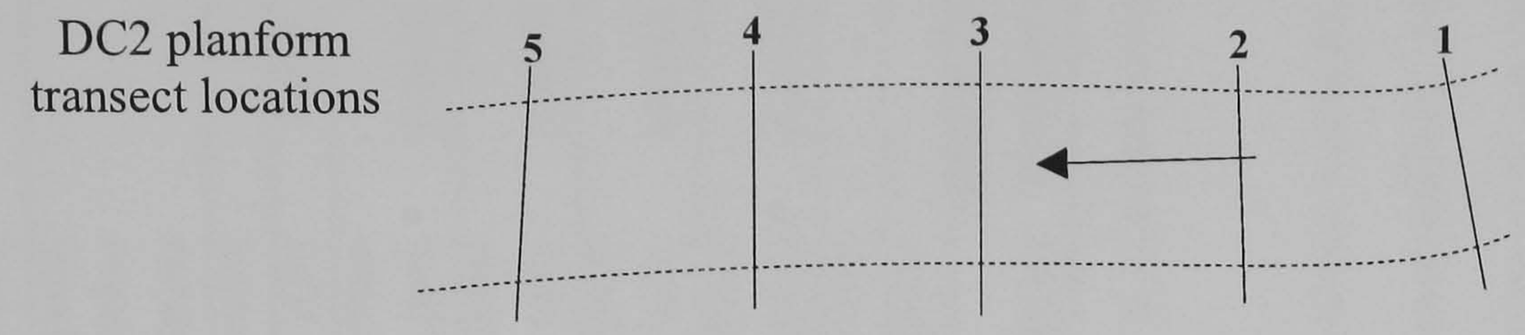
Transect 2, Fig 5.11) suggesting either the inwash of *ex situ* vegetative matter or the establishment of patchy or a thin vegetation cover within the palaeochannel.

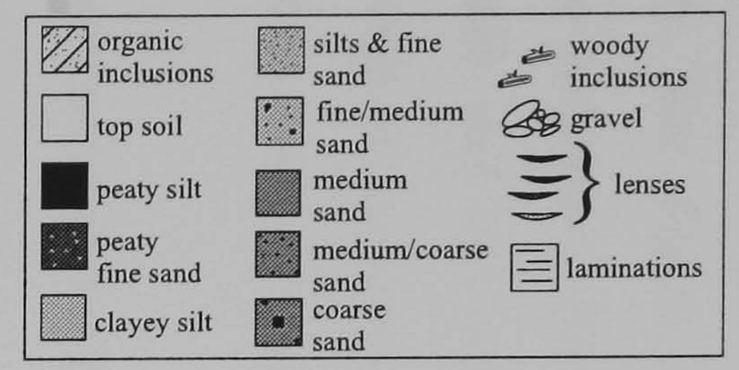
A fine grained infill deposit, comprising clays, silts and fine sand and containing organic material overlies the Sp and Sh facies in transects 2, 3, 4 and 5. These deposits are therefore laterally extensive and form an organic facies, Fsc, with a clay/silt/fine sand matrix. There is a degree of spatial variability in sedimentation as transects 1 and 2 contain a facies C comprising peaty silts (e.g. Core 12 Transect 1, Fig 5.11). The variability may result from surface depressions, which do not mirror the bed morphology and therefore may have been formed by localised scour potentially formed by flow through the channel during earlier stages of abandonment. The depressions encourage ponding or a discontinuous vegetation cover, with the peaty facies resulting from denser patches of vegetation development.

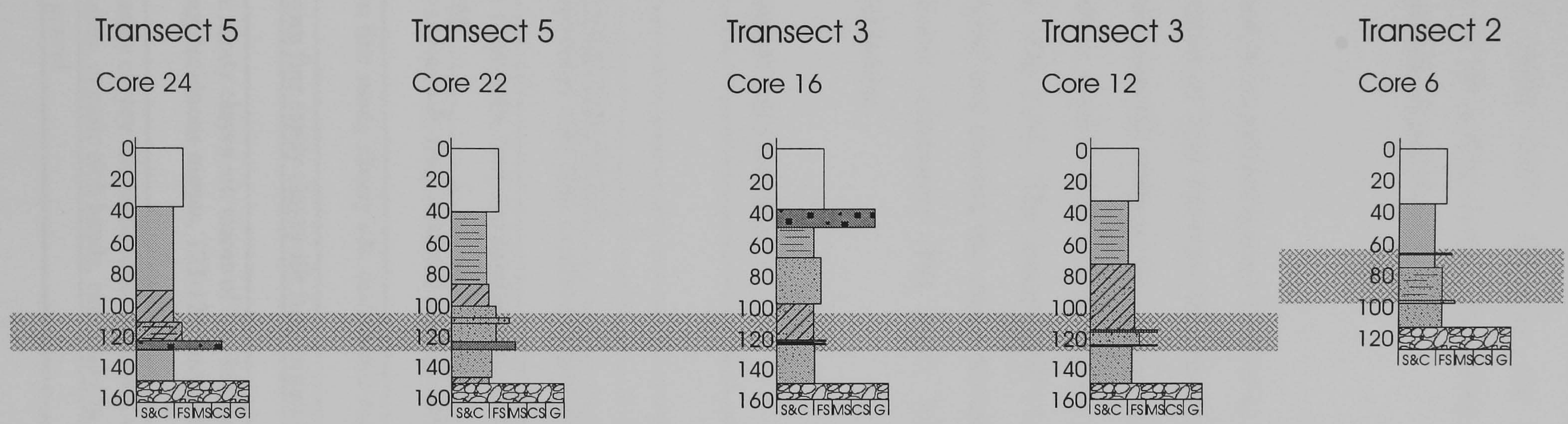
Within the Fsc and C facies are a series of coarser sediment horizons (Fig 5.13), evident for example in transect 3 (core 12), transect 4 (core 14) and transect 5 (core 22) at approximately 20cm from the gravel base, and in transect 2 (core 6) at 15cm above the gravel surface. Transects 5 (core 22) and 3 (core 12) also display two additional coarse horizons. The abrupt upper and lower boundary contacts, and increased grain size of these horizons infer their deposition during higher energy flows, therefore they can be interpreted as palaeoflood deposits from large flood events (cf. Baker *et al.* 1993). Further investigation would be necessary to correlate these events. However, from their comparable location within the stratigraphy (Fig 5.13), the flood layers are interpreted as being deposited during a period of higher flood magnitude and inundation.

Overlying the organic sediment facies, within all of the palaeochannel transects, are laminated clays and silts forming a uniform sediment horizon of up to 40cm depth (Core 8 Transect 1, Core 14 Transect 4 - Fig 5.11). These sediments have been grouped as facies Fm and interpreted as a period of overbank deposition of suspended fine sediments. A sporadic occurrence of oxidised organics within the facies probably results from the desiccation of formerly waterlogged organic remains. It signifies a thin former vegetation cover in and around the palaeochannel, but also that the preservation of the organic material has been limited by water table fluctuation. The low spatial variability in sedimentation within the overbank deposits may be related to a limited vegetation cover (Bridge & Leeder 1979). Moreover, continuous overbank sedimentation of clays and silts may have impacted upon the development of a vegetation cover (Amoros & Bornette 1999). The most recent infill

Dovecote Palaeochannel 2 (DC2) Palaeoflood Sediments







sediments within palaeochannel DC2 form a veneer of poorly developed top soil, facies P which presently has a thin covering of vegetation (Plate 5.3). This facies delineates the upper limit of the sedimentary record.

In summary, the facies sequence for palaeochannel DC2 depicts a fining upwards sedimentary sequence (Fig 5.12) and, therefore, a progressive de-coupling between the palaeochannel and the active channel (Allen 1965). However, the laminated overbank sediments indicate continued influence of the active channel following abandonment while palaeoflood horizons relate to high magnitude flood events.

5.2.3 Plant macrofossils

A 158cm deep core (Table 5.3) extracted from palaeochannel DC2 (Fig 5.9) was sampled at 5cm intervals to 80cm depth and thereafter at 2cm intervals for plant macrofossil analysis. Above 80cm depth oxidisation of organic material reduced the preservation potential of plant macrofossils. Loss on ignition (LOI) values, a proxy indicator of organic matter content, were obtained for each macrofossil sample (Fig 5.14). The macrofossil stratigraphy has been divided into zones as a means to describe and discuss the characteristics of, and temporal changes to the composition to the fossil community (Fig 5.14). The composition and interpretation of these zones is described below.

Table 5.3 Palaeochannel DC2 Plant Macrofossil Core Log

Depth	Transition (from above)	Description	Facies Code
0-23		compression	
23-43		dark brown, fine sandy clay, top soil	P
43-48	graded	mottled light grey/orange silty clay, oxidised organics root penetration	Fm
48-57	graded	light brown grey clayey silt, freq. oxidised organics, 54-56-organic band-darker brown	Fm
57-76	graded	light brown grey clayey silt, freq. oxidised organics mottled structureless	Fm
76-86	graded	reddy grey brown fine sandy clayey silt, occasional organics, structureless	Fsc
86-100	sharp	light medium brown fine sandy clayey silt freq. organics	C
100-106	-	contamination	
106-126	-	reddy brown fine sandy clayey silt traces of fine laminations freq. organics including deciduous matter, 123-124: reddy fine silty sand flood horizon	Fsc
125-158		brown/red fine sandy clayey silt, occasional organics, occasional fine sandy silt lenses, organic rich bands, especially in lower section	Sh
158+	sharp	coarse sand and gravel	Gm

Dovecote Palaeochannel 2 (DC2) Plant Macrofossil and Core Log Data

top soil
peaty fine sand
silts & fine sand
laminations
lenses
peaty silt
clayey silt
fine & medium sand
organic inclusions
gravel

Zone 1 extends from the bottom of the macrofossil core to 147cm depth and consists of a diverse fossil community including the wetland species, *Juncus* spp., and *Cladium mariscus*, aquatic species including *Nitella* spp., *Chara* spp., *Ranunculus aquatilis* and the aquatic fauna *Plumatella*, and *Daphnia* ephippia (Cladoceran egg cases), alongside wide niche species and ruderals (Fig 5.14). Wells & Wheeler (1999) found *Chara* spp. in cores from the Norfolk Broads which were interpreted as the effect of flooding and inundation, whereas Tobolski & Ammann (2000) interpreted the dominance of *Nitella* oospores in the fossil record as an indication of low nutrient conditions. In addition, *Ranunculus aquatilis* was regarded by Jones (1956) as a dominant species in a slow flowing former branch of the River Rheidol. Therefore, the oldest section of the fossil record of DC2, dating to around 2440-1920cal. BC indicates a predominantly, aquatic community, with low nutrient status.

The sedimentary conditions of macrofossil zone 1 correspond with the lower part of the medium-fine sand facies Sh, a period of sedimentation which reflected a continual connection between the main river and palaeochannel (Fig 5.12). Due to the spatial distribution of facies Sp which underlies Sh, the oldest palaeochannel sediments are not found in the macrofossil core (Table 5.3). Charophyte algae are known to deposit large seed banks (Bornette *et al.* 1996a); therefore as the sediments of zone 1 infer high rates of sedimentation and limited autochthonous organic matter accumulation, the oospores could be of extra-local origin. However, the presence of *Chara* and *Nitella* in aquatic communities is common and they are known as rapid colonisers of newly formed aquatic habitats (Rodwell 1995, Birks 2000) therefore their presence and that of *R. aquatilis*, do not conflict with the habitat conditions suggested by the sedimentary characteristics. *Juncus* spp. are also known to be rapid colonists of riverine wetlands (Lazenby 1955). Conversely the presence of *Stellaria media* and *Cerastium fontanum*, found on fertile, sometimes damp, ground suggests transportation prior to deposition. *Cladium mariscus* is found in fen peat (Rodwell 1995) therefore its presence in the fossil record also appears to be anomalous, as the sedimentary record and loss on ignition values (LOI-Fig 5.14) suggests a limited presence of organic material. As *C. mariscus* is persistent within the fossil record, however, the community from which it originates may have been proximal to DC2. Overall, the fossil record of zone 1 infers an aquatic habitat, however, due to the high sedimentation rates and limited organic matter, interpretation of the fossil record is tentative.

The macrofossil record in zone 2, from 147 to 120cm depth, contains species with a continuous presence from zone 1 including *Juncus* spp., *Cladium mariscus, Alnus glutinosa,*

Rumex spp. and a few aquatics (Fig 5.14). This zone also sees the emergence of hitherto absent species including *Carex* spp., *Cerastium fontanum, Potamogeton* spp., *Alisma plantago-aquatica*, and *Prunella vulgaris*. Zone 2, therefore, comprises both aquatic and wetland communities and while many of the species present in zone 1 persist up to zone 2, the introduction of several new species indicates a change in habitat composition. Firstly, the presence of *Potamogeton* spp. and *Alisma plantago-aquatica* suggest a development of the aquatic habitat within the palaeochannel, with *A. plantago-aquatica* associated with the progressive infilling of the palaeochannel which has resulted in increases to the nutrient content of the habitat (cf. Bornette *et al.* 1994d). Zone 2 lies within facies Sh, however, the underlying fine sediments, deposited during earlier stages of infilling, can account for the increase in nutrient content and may have provided a more suitable substrate for vegetation establishment (Hupp & Ostercamp 1985). The persistent presence of *Daphnia*, *Plumatella* and *Nitella* verifies the presence of standing water in the palaeochannel.

Cerastium fontanum and *Prunella vulgaris* are frequently found co-existing on moist fertile ground (Grime *et al.* 1990). Their presence, and that of *Carex* spp. within zone 2, indicate the accumulation of a fertile, more organic-rich substrate and increases in the nutrient status of the palaeochannel. The aquatic environment of DC2 would not be suitable for the establishment of these wetland species and, therefore, the species most probably represent either *ex situ* material or the dual presence of two communities (aquatic and wetland) within the palaeochannel. The wetland species have both a persistent presence and are well preserved (with no indication of degradation) which suggests deposition close to the parent plant (Huber & Ferguson 1998). The sedimentary conditions of the palaeochannel within zone 2 infer the dominance of *ex situ* inputs with only moderate amounts of organic matter infilling (LOI, Fig 5.14), which may account for the singular presence of species including *Rubus* spp., *Rumex acetosa* and *Persicaria hydropiper* within the fossil record, all of which are not found in aquatic habitats, but are frequently found in *ex situ* deposits (Abernethy & Willby 1999).

The macrofossils from zone 2 suggest the presence of duel vegetation communities, an aquatic community, due to inundation and high water tables and a patchy wetland community at the shallower, possibly less disturbed sections of the palaeochannel, experiencing more autochthonous organic matter infilling. The macrofossil record and infill sediments, thus, indicate the potential spatial variability in palaeochannel environments. Furthermore, a number of cores contained vegetative matter within the facies Sh (e.g. core 12, transect 2, Fig 5.11), which may signify patchy vegetation development. Similarly, Bornette & Amoros

(1991) found that zonation in vegetation types occurred in former braided river channels due to the variable hydrological inputs resulting in the synchronous presence of different vegetation communities.

Plant macrofossil zone 3, between 120 and 105cm depth, consists of persistent species from zone 2 including the emergent *A. plantago aquatica*, wetland plants *Juncus* spp. and *Carex* spp., the tree species *A. glutinosa*, and wide niche species *C. fontanum*. The aquatics *Potamogeton* spp. and *Nitella* remain but their presence is sporadic (Fig 5.14). *Callitriche* spp., also an aquatic plant, which appeared towards the end of zone 2 are persistent throughout zone 3. The composition of the fossil record, therefore, shows only minor changes including a reduced hydrophyte community. This sporadic presence of hydrophytes and *Nitella* and an absence of limnic fauna (Fig 5.14), infer a reduced area of ponded water. The only other significant change in the macrofossil record is the establishment of *Callitriche* spp., a species found in frequently disturbed aquatic habitats (Jones 1956, Abernethy & Willby 1999). The sedimentary record, incorporating the upper part of the Sh facies, and lower part of the C and Fsc facies (Fig 5.12), which correlates with the upper part of macrofossil zone 2 through to zone 3, shows the deposition of palaeoflood horizons, laterally extensive within the transects (Fig 5.13). Furthermore, the sediments lying above the flood layers have a higher organic content and reduced fine sand content, inferring increased vegetation cover and, hence, a reduction in high magnitude flooding or sedimentation rate. The effects of the period of flooding therefore includes terrestrialisation with the reduction of the aquatic community and an expansion of the palaeochannel vegetation cover (Stromberg *et al.* 1997).

Flood inundation is thought to supply a large number of propagules to cut off channels instigating a more diverse wetland community (Amoros & Bornette 1999). However, there is little evidence in macrofossil zone 3 for further increases in the number of wetland species or a change in the nutrient status of the habitat. Anomalous macrofossils within the flood layer of the macrofossil core include only *Stellaria media* and *Persicaria* spp., both of which are ruderal plants, the seeds of which are frequently found in flood sediments (Abernethy & Willby 1999). Flood scour and vegetation destruction may have occurred during inundation as, due to the low vegetation cover, the velocity of the inundation was not retarded (Amoros & Bornette 1996). In addition, the limited depth of flood sediment and sedimentation patterns infer that there was little change to the overall geomorphology of the palaeochannel and hence no development of regeneration niches for pioneer vegetation establishment. Lastly, in the case of a persistently high water table, and continuous overbank sedimentation of fines,

vegetation succession can be retarded or stagnated (Pautou & Decamps 1985) which could account for the limited amount of change within DC2 following inundation.

The macrofossil record in zone 4, from 105cm to the upper limit of the fossil record, is affected by aerobic conditions within the sediments and the oxidisation of organic material, which results in a decline in the numbers of species present (Fig 5.14). Those preserved include *Juncus* spp., *Glyceria fluitans* and *Carex* spp. as well as occasional grassland and wide niche species. The macrofossil composition thus indicates a wetland and wet grassland community. With only *Glyceria fluitans*, *Juncus* spp., and *Carex* spp. showing a persistent, but limited, presence in the fossil record, it is unclear if this could be attributed to poor preservation conditions or the actual former characteristics of DC2. The sedimentary conditions for zone 3, associated with the upper part of the Fsc facies as well as the laminated clays of facies Fm, indicate a thin vegetation cover, with a low organic substrate content (LOI, Fig 5.14) and silt/clay overbank sedimentation (Fig 5.12). The sedimentary data for the upper part of DC2 therefore may attribute the low numbers of species presence and limited organic content of the sediments to the persistently high water table (Pautou & Decamps 1985) and excessive deposition of fines (Bornette *et al.* 1994a). The macrofossil record may, however, merely represent the oxidisation of remains and degradation of plant macrofossils.

5.3 Results and Analysis for Palaeochannel DC4

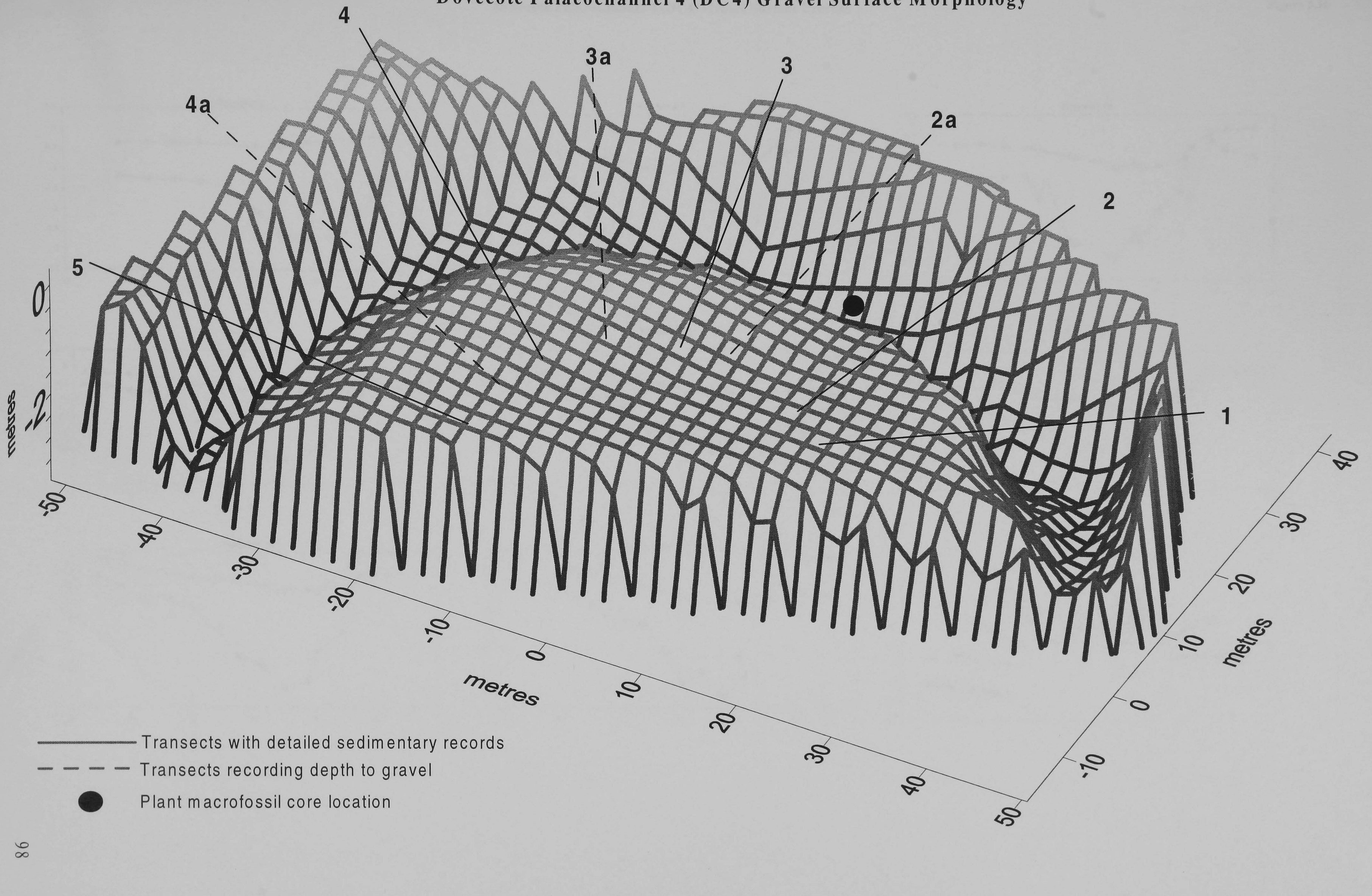
Palaeochannel DC4, associated with terrace unit T6 (Fig 5.1) is a former meander bend following the line of the terrace bluff of T5 (Plate 5.4). The surface geomorphology suggests that the channel was abandoned *via* chute cut-off. The full meander bend was subjected to detailed sedimentological and plant macrofossil analysis. Radiocarbon dates obtained from basal organic sediments indicate that palaeochannel infilling began at 1410-1620cal.AD (Table 5.1).

5.3.1 Palaeochannel geometry

Eight transects along palaeochannel DC4 were cored at 2m intervals and at higher resolutions to ascertain change of slope where necessary. Each core location was surveyed (Fig 5.16). From the cores extracted along transects 1 to 5, sediments were logged to ascertain the

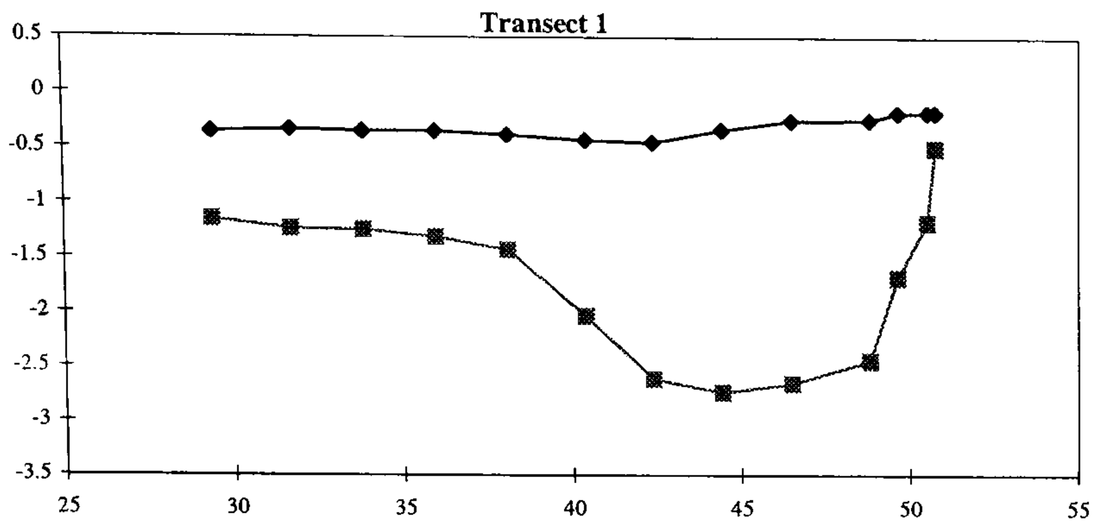
Figure 5.15

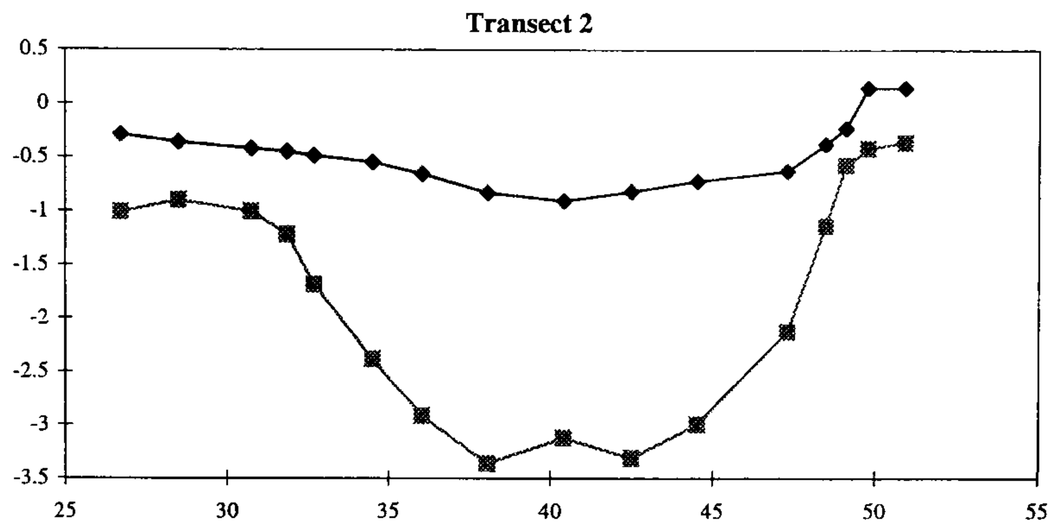
Dovecote Palaeochannel 4 (DC4) Gravel Surface Morphology

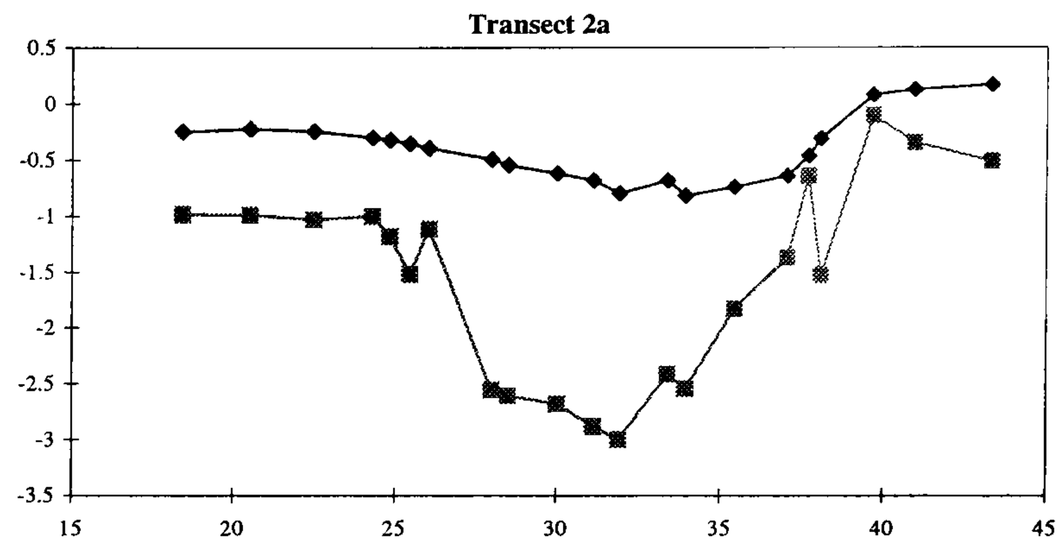


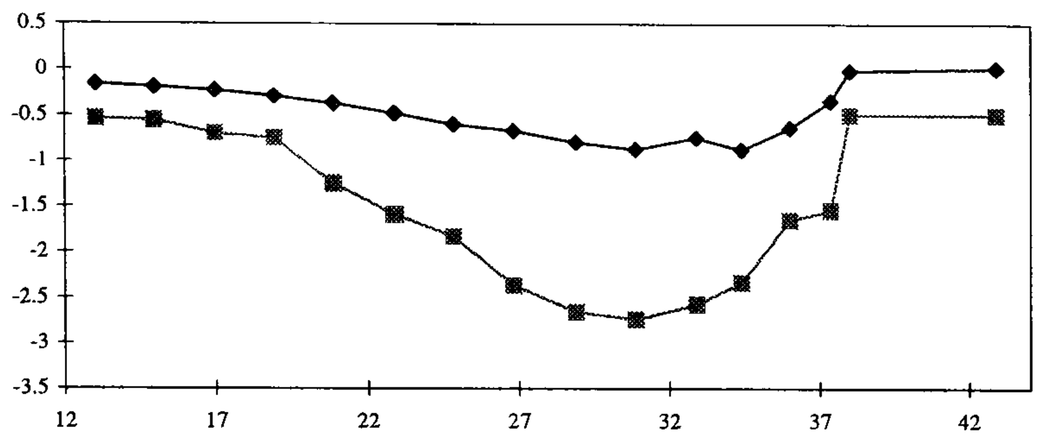
Dovecote Palaeochannel 4 (DC4) Gravel Surface Profiles

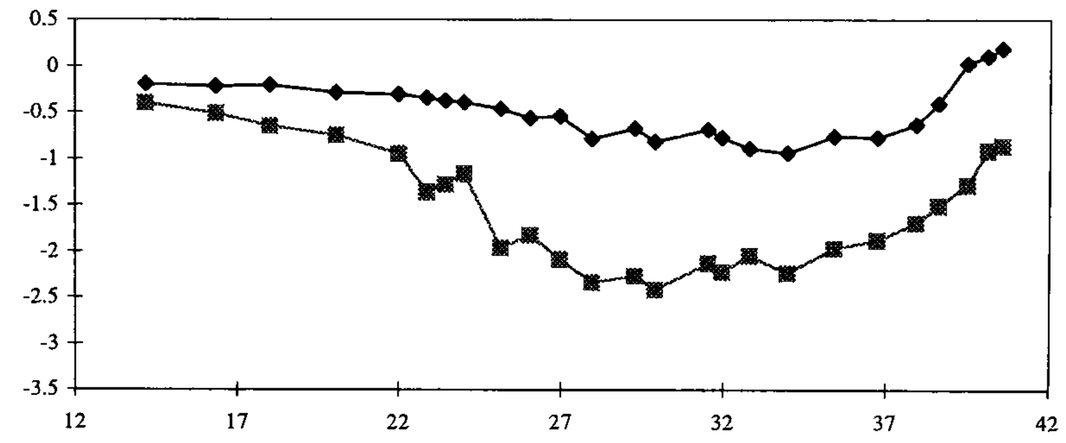
Figure 5.16

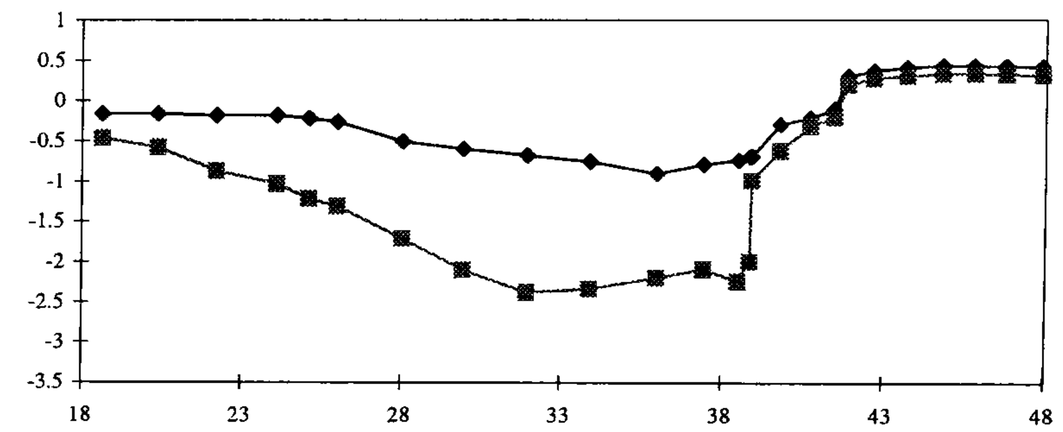


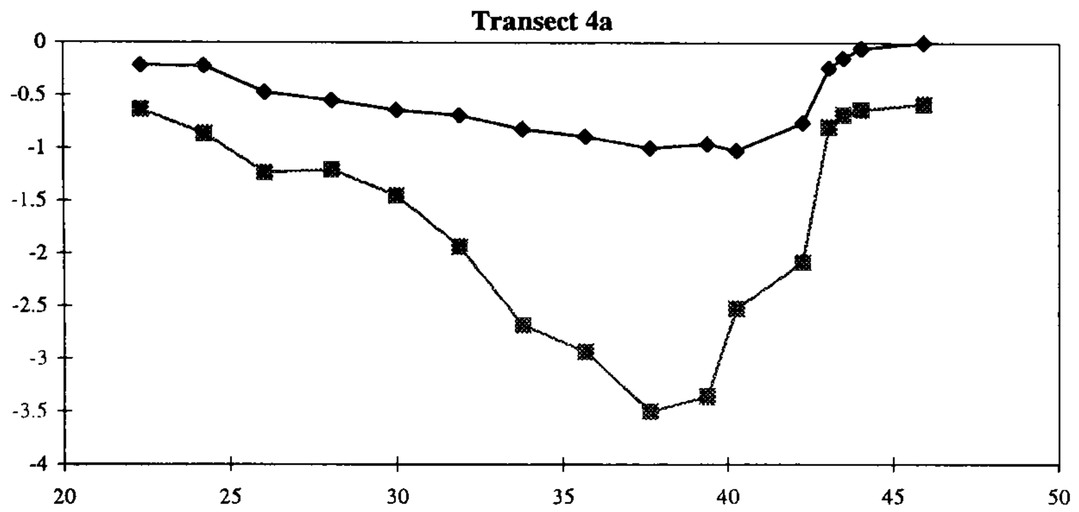


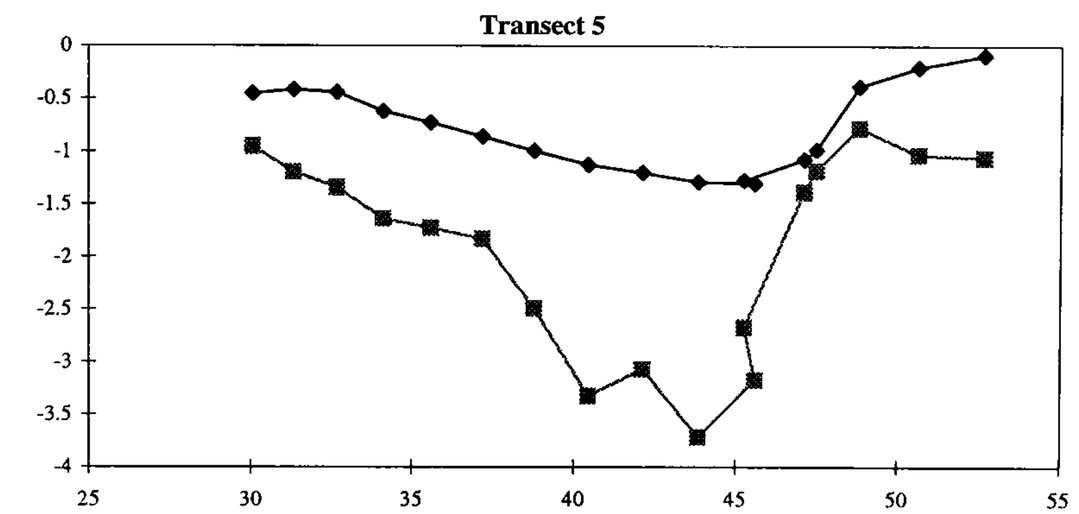


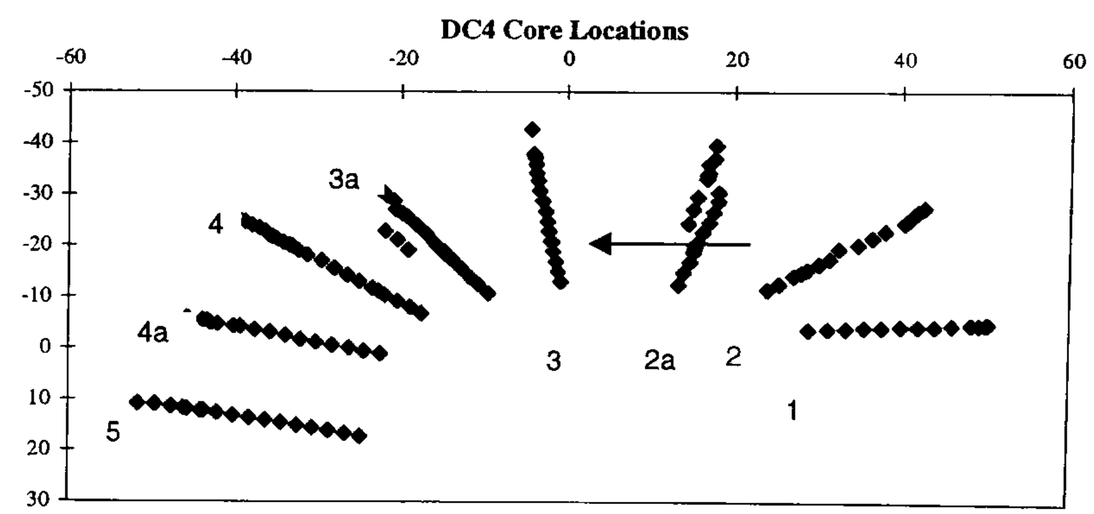












character of palaeochannel fill sediments. From the cores taken along transects 2a to 4a, depth of palaeochannel fill was recorded.

The reconstruction of the gravel surface morphology of DC4 revealed the form of a meander bend (Fig 5.15) as also seen from the surface geomorphology. The channel has well defined steep banks on the right channel side, and lower gradient slopes on the inside of the meander bend. The cross section profiles for transects 1 and 2 (Fig 5.16) show the channel to be more symmetrical and deeper at the upstream end while the downstream section of the meander is wider and shallower than the rest of the reach. At the downstream end of the palaeochannel reach, transects 4a and 5 show a deepening and narrowing of the channel with increasing asymmetry towards the deeper part of the channel, confined to the right bank.

From the surface geomorphology, the palaeochannel reach represents a meander chute cut-off while the former meander channel bed form is also evident from the gravel bed morphology. The steep slopes of the former channel on the outer meander bend (Fig 5.16) indicate bank erosion of older fluvial deposits prior to abandonment. The inside meander bend slopes are lower than the outer, with the lowest inner bank gradients at the downstream end of the reach. This morphology, with the increasing asymmetry of the channel specifically on transects 3a, 4 and 4a, (Fig 5.16) is interpreted as reflecting point bar development. As the channel is deeper at the upstream end, shallows to transects 3a and 4, then becomes deeper and confined at the downstream end, a pool-riffle-pool sequence may be evident.

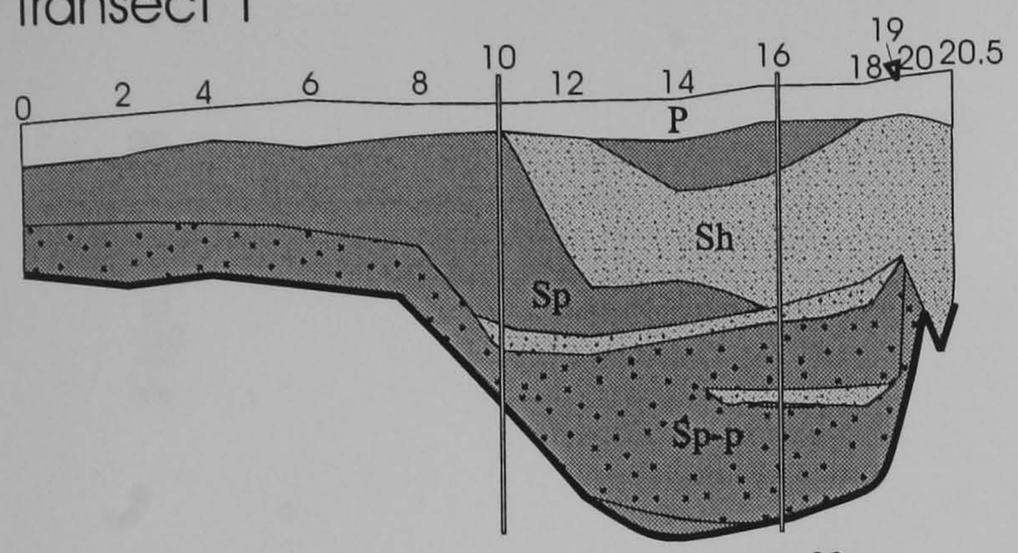
5.3.2 Lithostratigraphy of channel fills in palaeochannel DC4

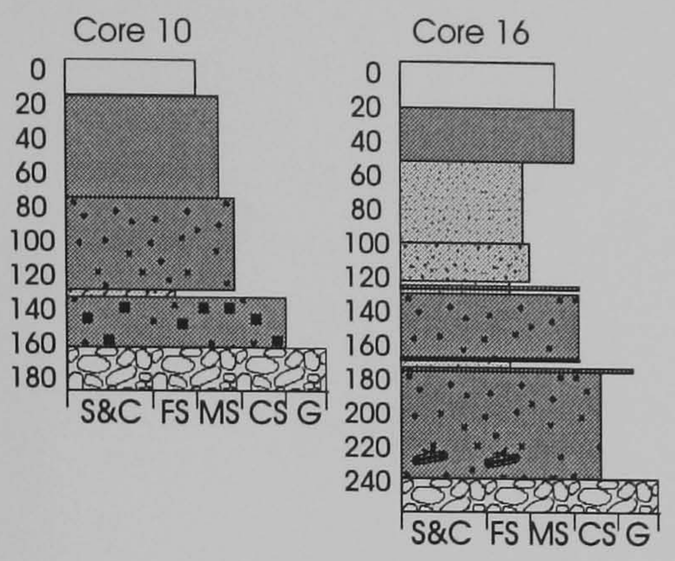
The character of palaeochannel fill sediments was logged for five of the eight transects across palaeochannel DC4. The results of sediment coring are represented in Fig 5.17 with the transects running from upstream (transect 1) to downstream (transect 5). Using the lithofacies classification (Table 4.2) the sediments described above have been divided into facies representing specific depositional environments. Each facies is described and discussed below while the sequence of palaeochannel infilling is shown in Fig 5.18.

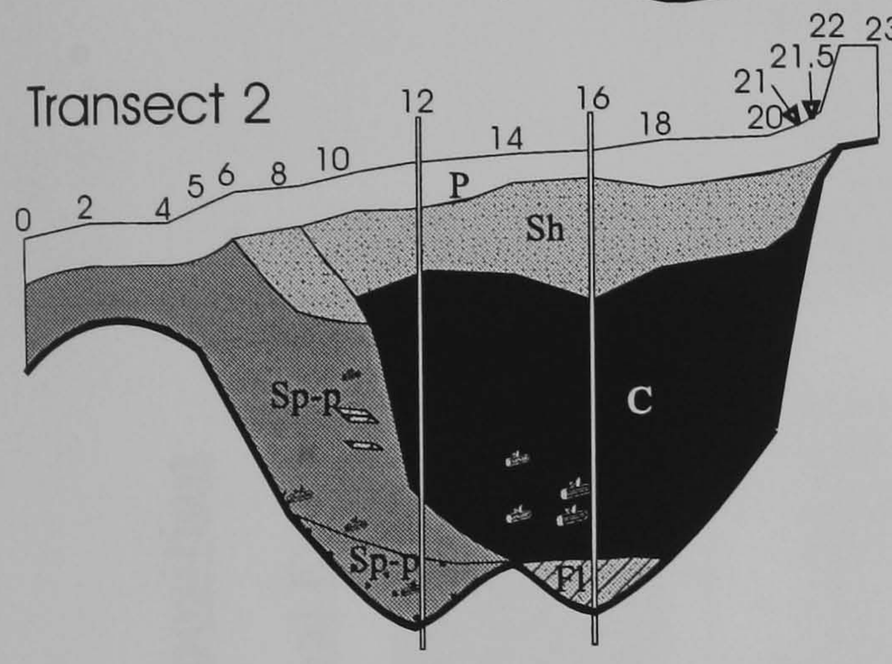
Overlying the left bank, or point bar, of transect 5 is a thin layer of coarse sand which is the only evidence for coarse sediment deposition on the downstream sections of the point bar. This coarse sand facies, Sp, is interpreted as deposition from the river's bed load when the channel was active (Etheridge & Schumm 1978). Transect 5 shows the channel to be confined and incised into the outer bend (Fig 5.16). This will have limited the competence of

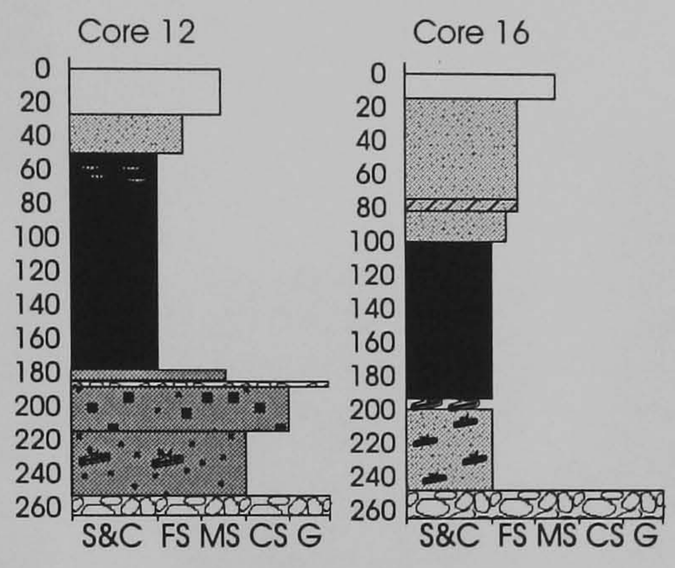
Figure 5.17

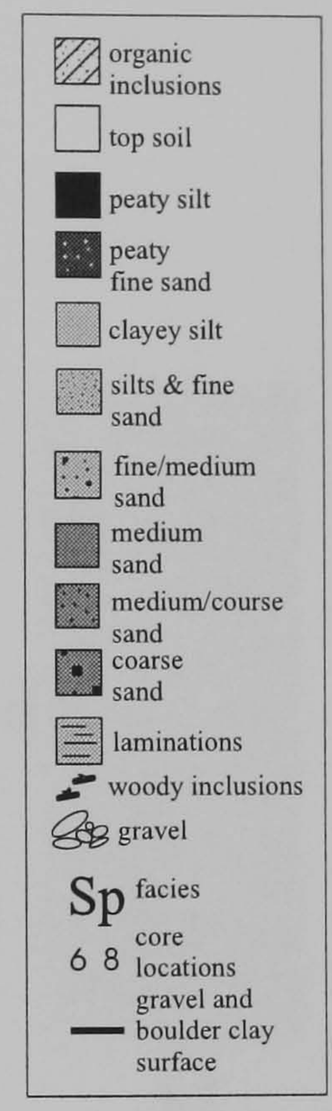
Dovecote Palaeochannel 4 (DC4) Sedimentary Infills

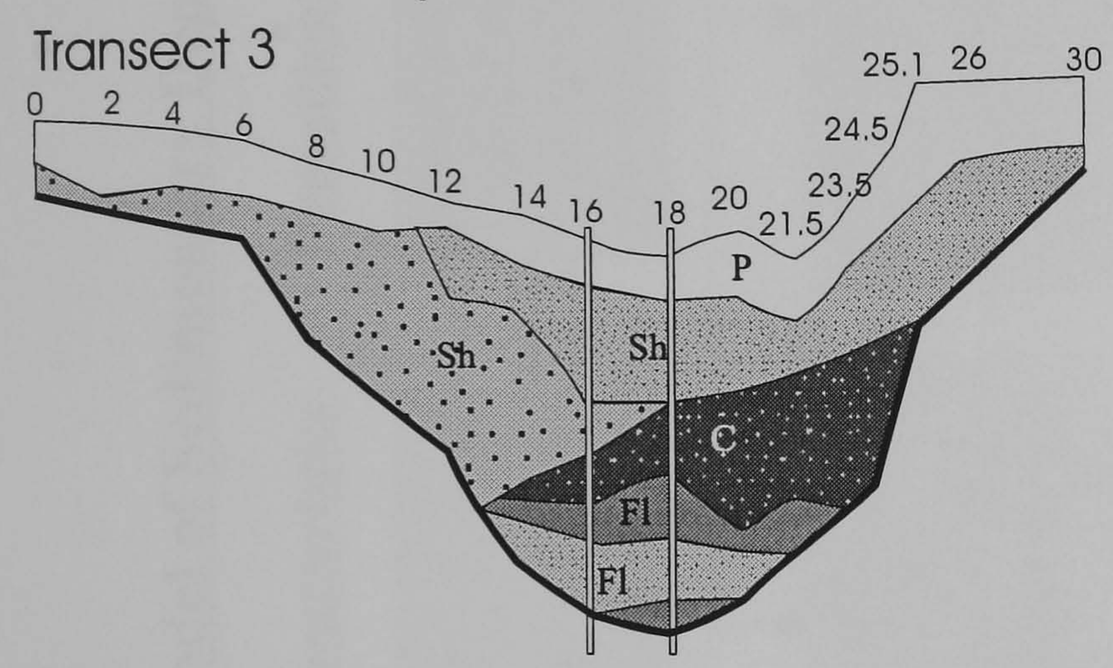


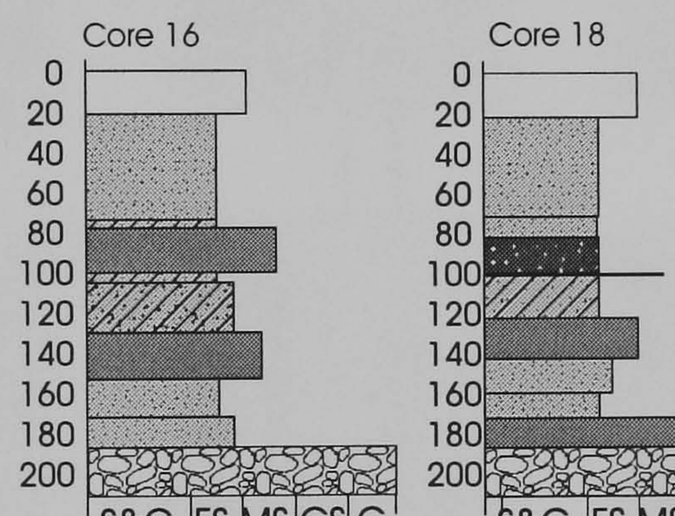


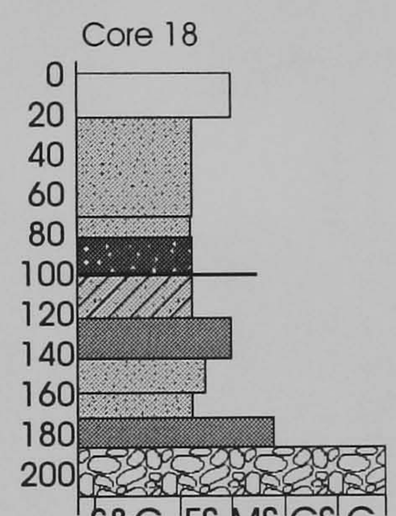


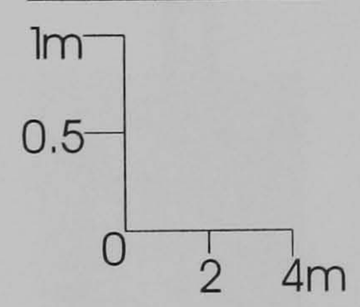


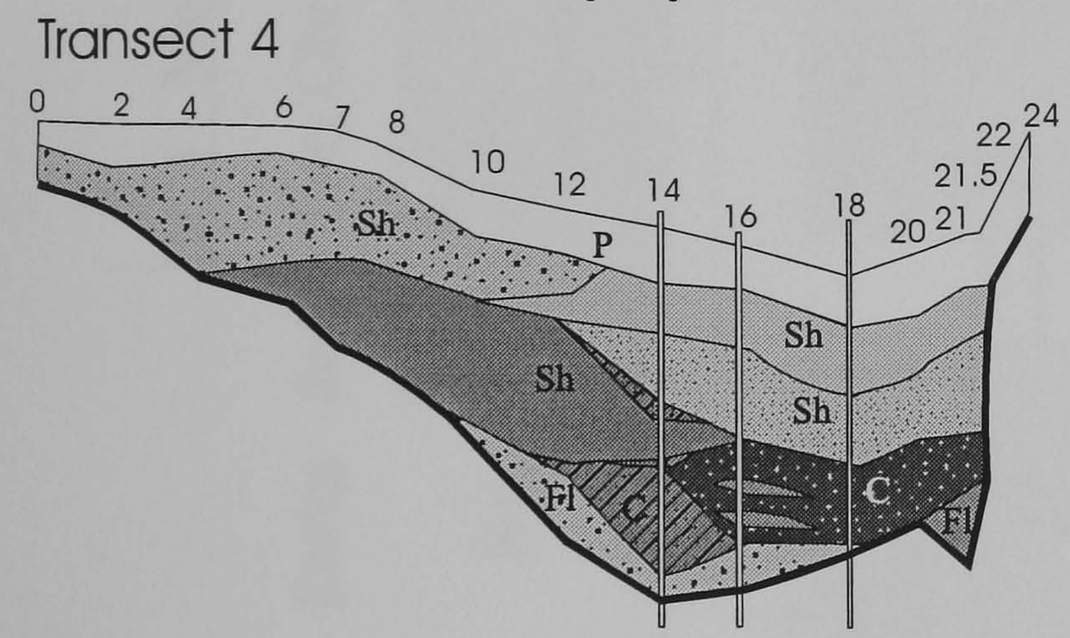


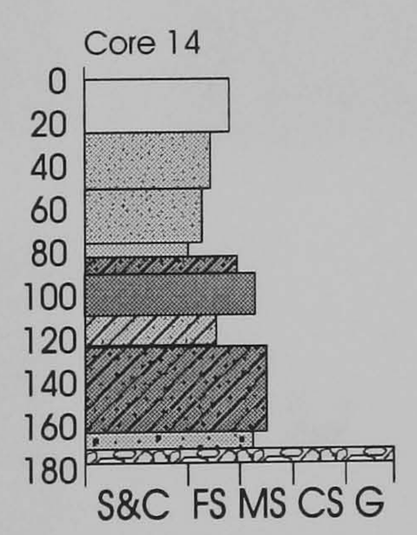


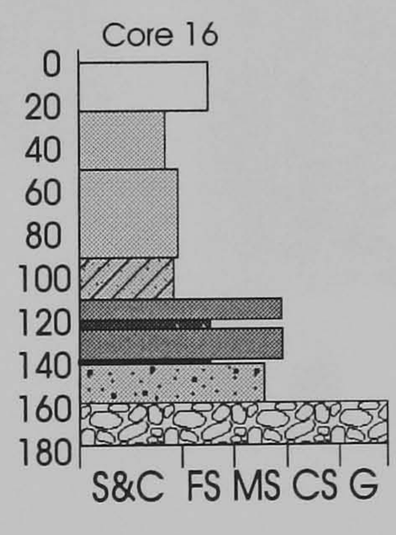


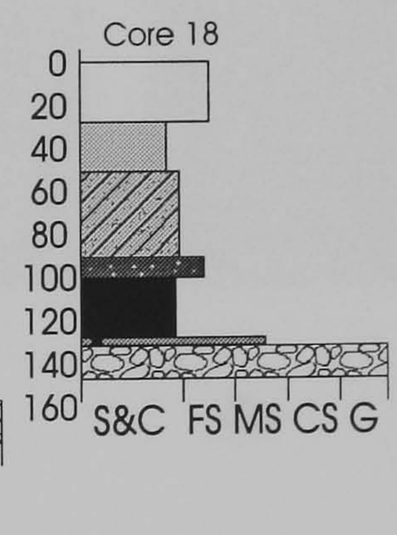


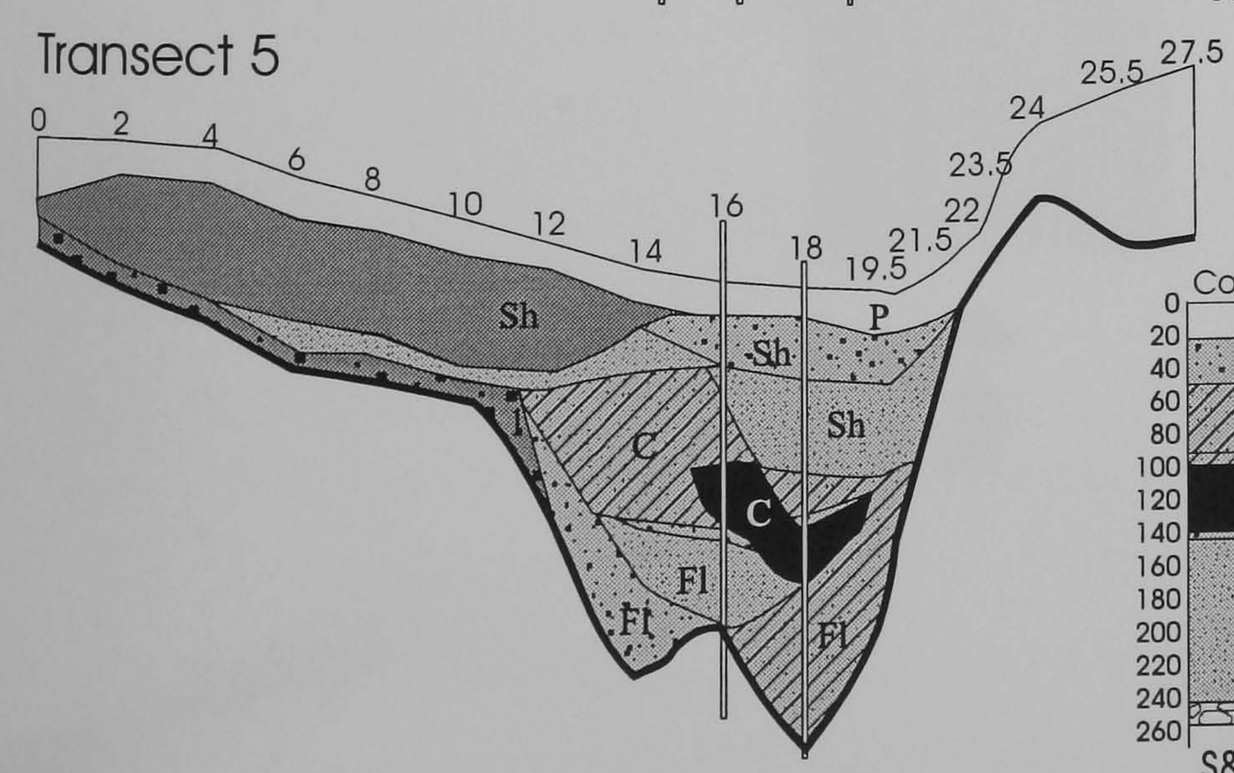


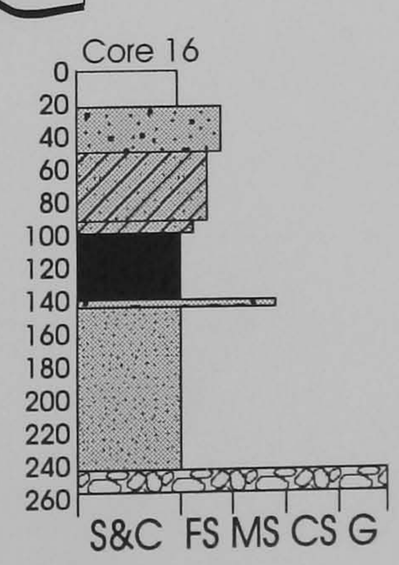


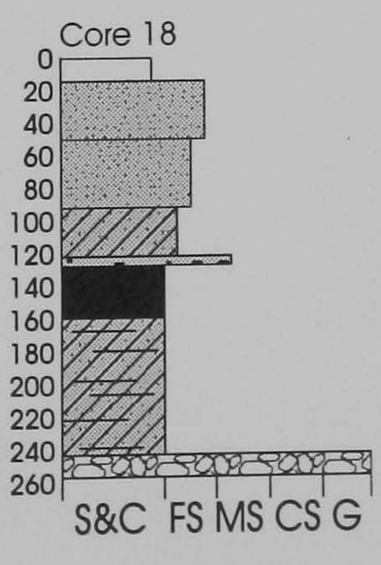












Left Channel Side

Right Channel Side

Figure 5.18

DC4 - Model of Sedimentary Deposition

Facies	*Sedimentary Characteristics*	Depositional Environment
Sp	*coarse sand, no structure, downstream point bar surface only*	lateral accretion/active channel deposits, high energy environment, pre-abandonment
Sp-p	*medium/coarse sand >1m depth-transect 1 edges-transect 2*	sediment plug deposited from bedload sediments, high sedimentation rates
Fl	*medium fine sands, lateral fining upstream (transect 5-transect 3)*	backwater deposits, downstream connection with main channel
C	*peaty silt & fine sands, less organic content downstream, spatial variability*	oxbow/wetland spatially variable vegetation cover, *in situ* organic matter accumulation
Sh	*medium sand, fine/medium sand deposits, laterally and vertically variable*	increased sedimentation, reduced vegetation cover/ density
P	*poorly developed top soil*	upper limit of overbank sedimentation

the flow on the inner side of the meander bend and enabled the accumulation and preservation of lateral deposits on the point bar (Brown 1997a).

Immediately above the gravel layer, transect 1 and the inner meander bend of transect 2 are infilled with an extensive medium/coarse sand deposit (Fig 5.17), which is up to a metre deep (e.g. Core 16 Transect 1), containing woody inclusions at the base. The sediments are an homogenous medium coarse sand facies, Sp-p, representing the rapid deposition of bed load following chute cut-off, which has formed an alluvial plug (Brown 1997a). This facies is prevalent in transect 1, lines the left channel side of transect 2, and exists as a thin medium sand deposit at the base of transect 3 (Fig 5.17). Conversely, above the gravel layer the downstream transects 3, 4 and 5 are infilled with fine/medium sands and fine sand deposits, which have infilled the depressions in the channel bed (e.g. Core 18 Transect 5 Fig 5.17). Following the abandonment of the channel *via* chute cut-off (Section 5.1), therefore, a dichotomy in the spatial sedimentation pattern exits.

The sedimentation of fine/medium sands and fine sands in the downstream transects (3, 4 and 5-Fig 5.17), above the gravel layer, is assumed to be coeval with or closely following the upstream alluvial plug development. The deposits form facies Fl and include a complex array of homogenous fine-medium sands (e.g. transect 5-core 16, transect 3, cores 16, 18 and 20) alongside sands containing vegetative matter (e.g. transect 4-core 14, transect 5-core 18). Occasional laminations were also evident. The facies indicate low energy, and reduced inundation, backwater deposition following abandonment and hence a period of continued connection of the downstream end of the palaeochannel reach with the main channel. The variability in grain size, with a fining from transect 5 to 3, derives from the reduction in energy with distance from the connection point with the main channel and potentially from secondary flow during backwater inputs.

Overlying the backwater sediments in transects 3, 4 and 5 are peaty fine sand and peaty silt deposits while transect 2 is dominated by an extensive peaty silt deposit (Fig 5.17). No equivalent organic sediments are evident in transect 1. These organic sediments form facies C and indicate reduced fluvial inputs and an increase in vegetation cover. In the lee of the sediment plug (transect 2), the predominance of facies C across the transect emphasises the influence of the alluvial plug in protecting this section of palaeochannel from fluvial inputs (cf. Bornette *et al.* 1994a). Following channel abandonment the water table remained high as signified by the backwater inputs, resulting in standing water in the lee of the sediment plug, and the presence of an oxbow lake type environment. The spatial extent of the peaty silts is

affected by the initial channel morphology with the lee of the plug being located in the former pool of the channel (Fig 5.15) thus making it deeper than transects downstream and more susceptible to ponding. The spatial variability in sedimentation is, thus, limited by both the initial higher surface elevations of the gravel surface downstream (transects 3 and 4), and the dichotomy of sedimentation patterns following abandonment.

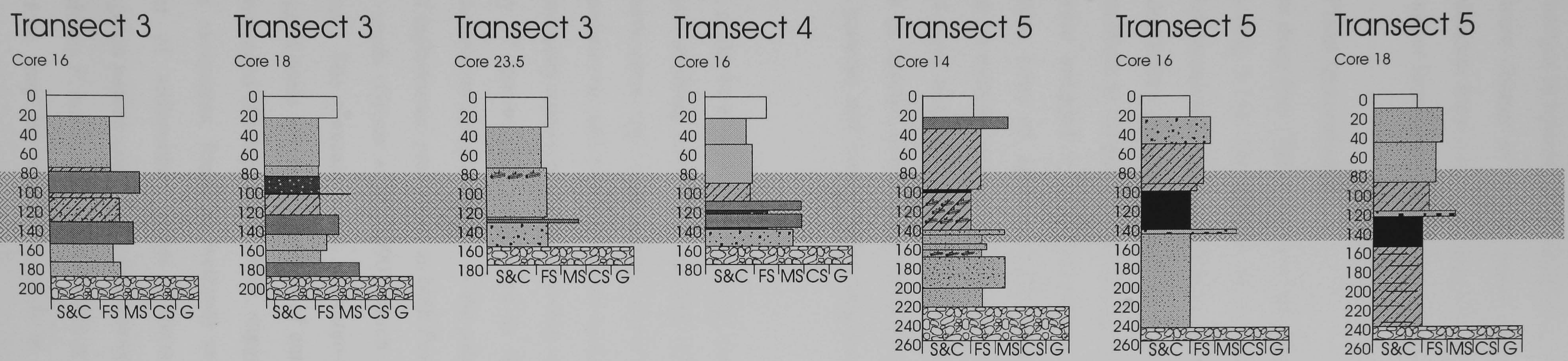
The C facies, overlying the Fl facies in transects 3, 4 and 5, exhibit slight differences in grain size to those of transect 2 (Fig 5.17), interpreted as the result of occasional backwater inputs experienced in the downstream section of the palaeochannel. The C facies signify a reduction in the influence of the channel and backwater deposition, and an increase in vegetation establishment. Decoupling of DC4 from the active channel may have resulted from processes occurring within the main channel, (i.e. lateral migration) or due to the increased height of the palaeochannel surface following alluviation (cf. Erskine *et al.* 1992).

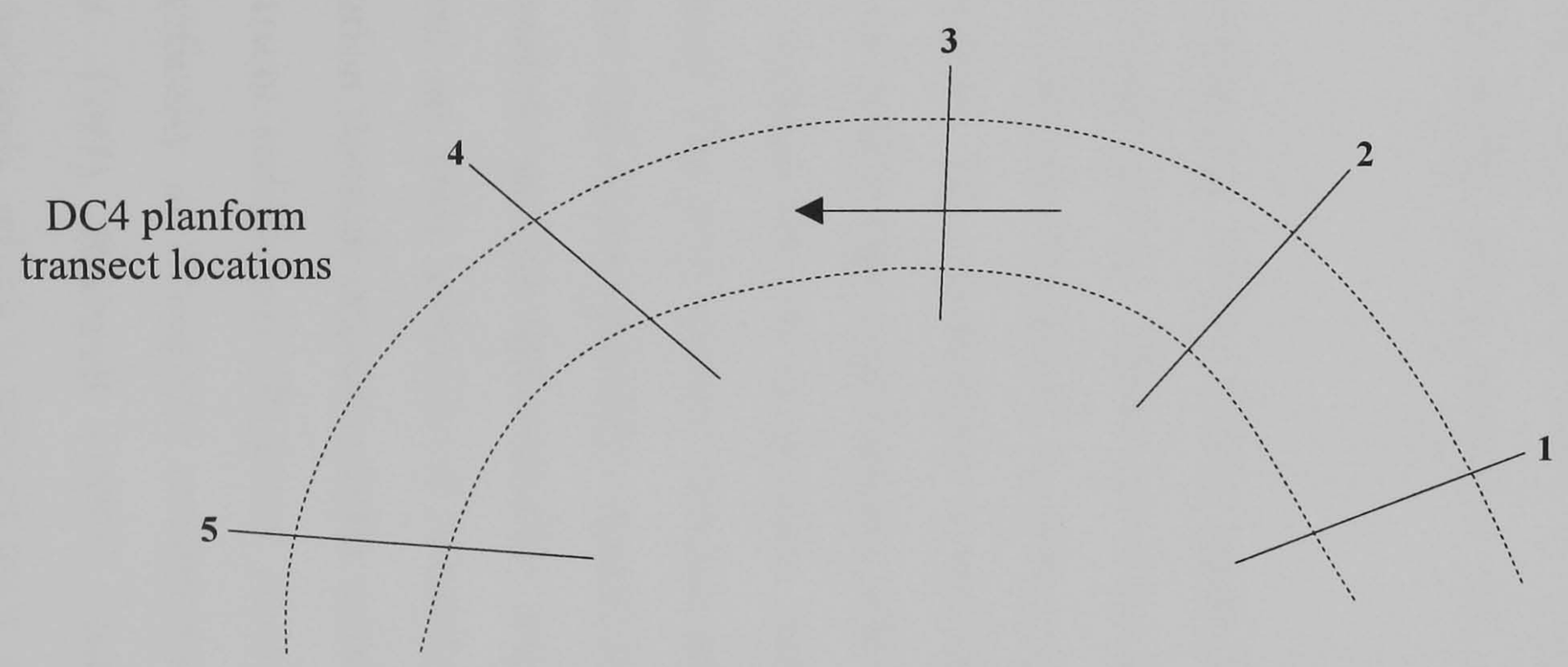
Within the C facies are coarse sediment horizons with sharp upper and lower boundary surfaces, indicative of inundation and higher sediment inputs (Fig 5.19). These sediments, interpreted as high magnitude palaeoflood horizons, are evident in transects 4 and 5, the lower at 124-139cm depth (core 16 transect 4) and 140cm depth (core 16 transect 5) and the upper at 111-120cm depth (core 16 transect 4) and 123cm depth (core 18 transect 5). Due to the extensive sediment plug at the upstream end of the palaeochannel, and the absence of flood horizons in the peaty facies in transect 2, it is likely that the deposits resulted from flood inundation from the downstream end of the channel. Furthermore, the presence of vegetation at the downstream section of the palaeochannel around transects 4 and 5 may have retarded the inundation and trapped sediment (cf. Bornette *et al.* 1998b) thus reducing the spatial extent of sedimentation.

Overlying the organic C facies in transects 2, 3, 4 and 5, and Sp-p facies (the alluvial plug) in transect 1 are infill sediments comprising silt and fine sand, medium/fine sand and medium sand (Fig 5.17). This array of laterally and vertically variable sediments have been grouped as a medium, fine-medium and fine sand facies, Sh, which includes laminated sediments. In comparison to the underlying facies, the deposits show a significant increase in the minerogenic content and change in grain size, although the contact is graded suggesting that the change in sedimentation, and consequent environmental conditions, was gradual (Fig 5.18). The facies reflect a reduction in vegetation cover, either anthropogenically induced or

Figure 5.19

Dovecote Palaeochannel 4 (DC4) Palaeoflood Sediments





Stratigraphic location of palaeoflood horizons

organic inclusions
top soil
peaty silt
peaty fine sand
clayey silt
silts & fine sand
fine/medium sand
medium sand
medium/coarse sand
coarse sand
woody inclusions
gravel
lenses
laminations

due to changes in hydrological conditions and an increase in sedimentation rate and therefore a significant change in fluvial inputs and sediment supply. The uppermost palaeochannel infill sediments form a top soil, facies P, across the whole reach, denote pedogenic processes and the upper limit of the sedimentary record.

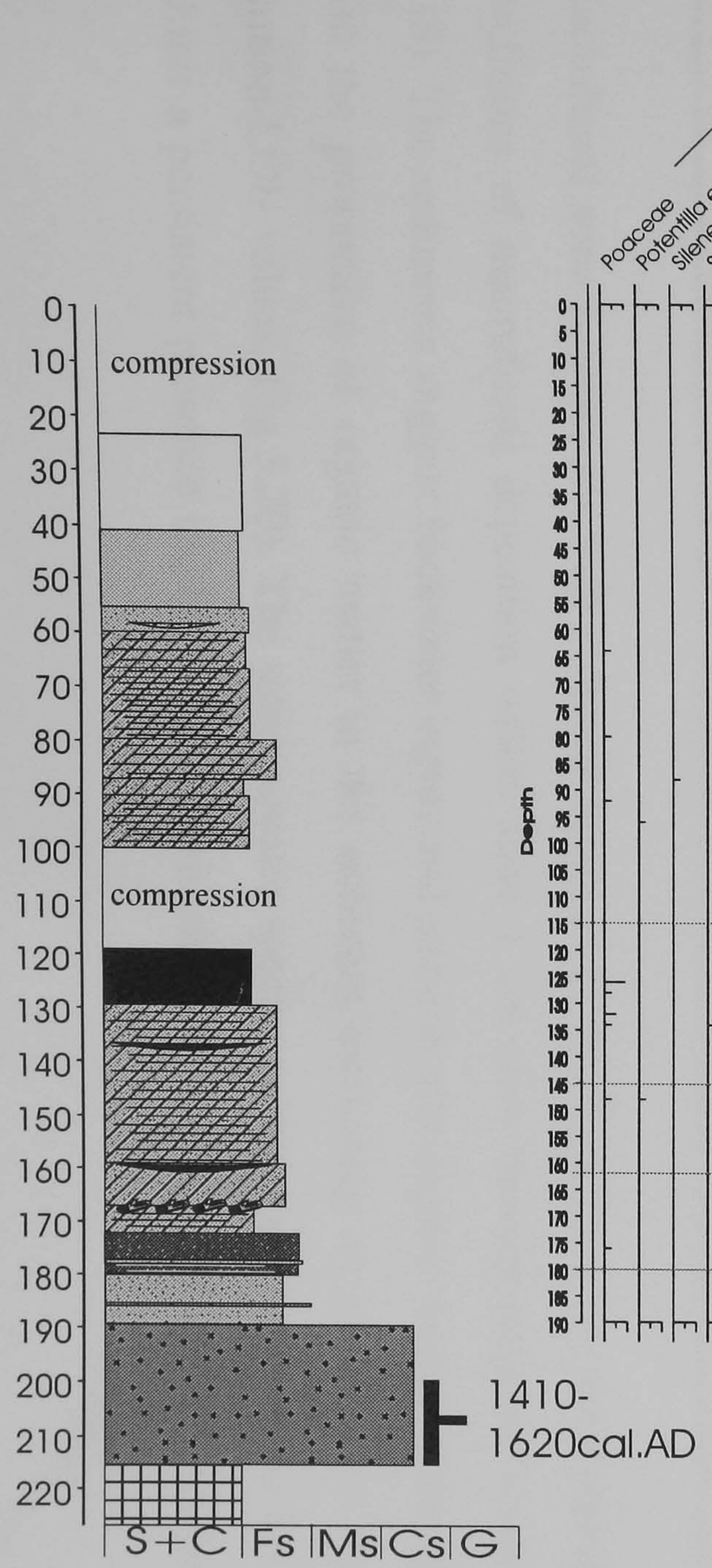
5.3.3 Plant macrofossils

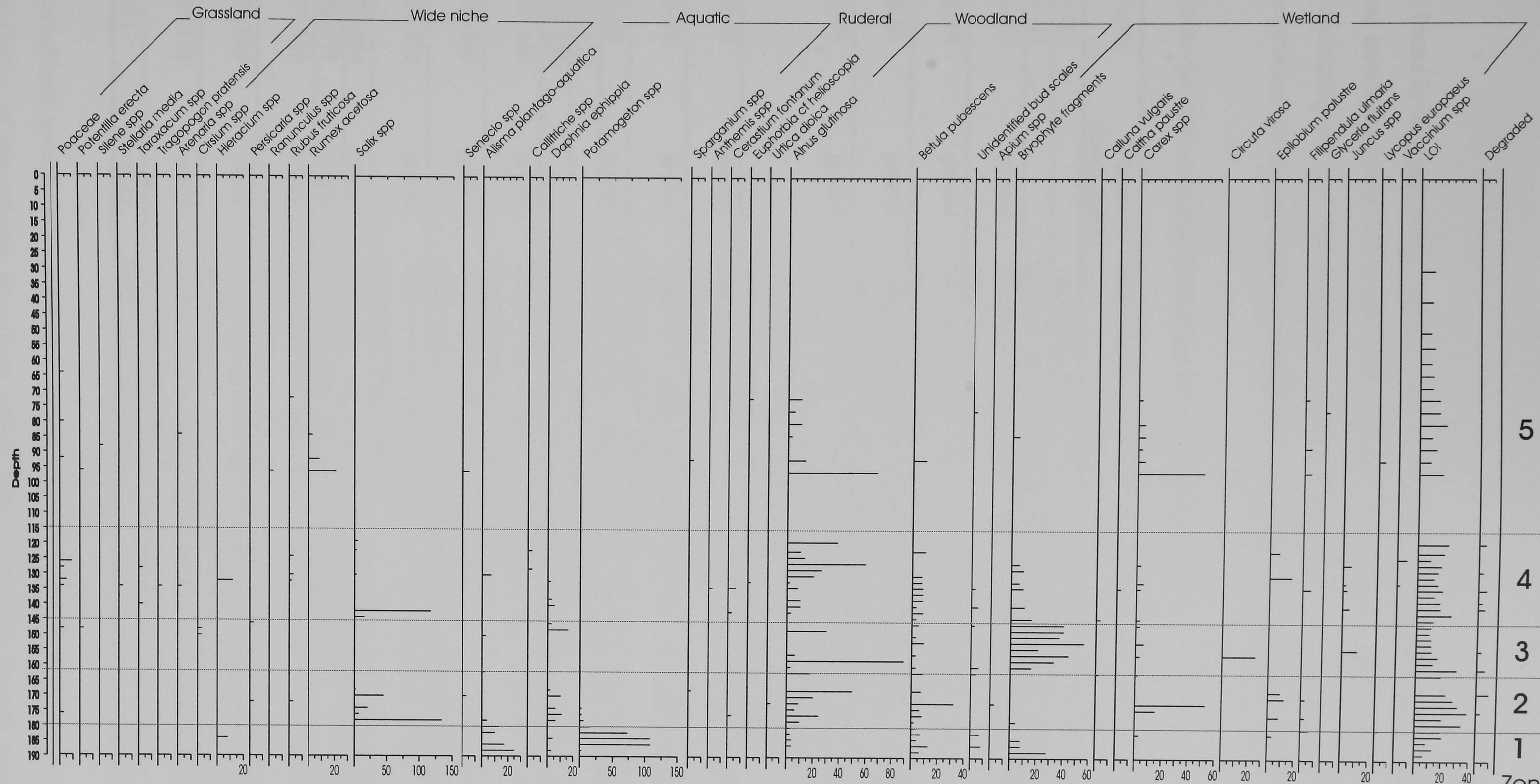
A 215cm deep core (Table 5.4) was extracted from palaeochannel DC4 for plant macrofossil analysis (Fig 5.15). The lowest 25cm of the core contained medium coarse sands which contained occasional vegetative matter (Table 5.4) but no plant macrofossils. From 190cm to 100cm depth the core was sampled at 2cm intervals, from 100 to 60cm depth at 4cm intervals and from 60cm to the present day surface at 10cm intervals for plant macrofossils. The upper 60cm were sampled at lower resolution due to the degradation of organic matter *via* oxidisation. Loss on ignition (LOI) values which denote organic matter content, were obtained for each macrofossil sample (Fig 5.20). The results of the plant macrofossil analysis for DC4 have been divided into five stratigraphic zones according to species present and changes in species composition throughout the core (Fig 5.20) in order to describe and explain patterns and trends within the fossil record. Each zone is described and explained below.

Zone 1, at the bottom of the core spans from approximately 190 to 180cm depth (Fig 5.20) and began infilling *circa* 1410-1620cal AD. It is dominated by *Alisma plantago-aquatica*, and *Potamogeton* spp., both aquatic species, with bryophyte fragments, *Lycopus europaeus*, *Betula pubescens*, and *Alnus glutinosa* seeds also present. The composition of species in zone 1 thus probably represents a slow flowing side arm or oxbow lake type habitat, with a limited diversity of species and, as denoted by the few wetland species or grasses, unvegetated exposed surfaces along the edges of the palaeochannel. The poor species richness may be the result of taphonomic processes, as both *Potamogeton* and *Alisma plantago-aquatica* produce durable seeds (Grime *et al.* 1990) which can therefore survive unfavourable preservation conditions. The presence of *A. plantago-aquatica*, an early colonist of recently created waterlogged areas where the process of eutrophication through organic matter accumulation has commenced (Grime *et al.* 1990), suggests nutrient enrichment (Bornette *et al.* 1994d). *Lycopus europaeus,* found in wetlands and, specifically in floodplain environments, is a coloniser of sedimentary plugs (Pautou *et al.* 1997). Rodwell (1995) identified a *Potamogeton natans* community in contemporary wetlands, which is species poor, and often only includes *P. natans* and a small number of emergents such as *A. plantago-aquatica*. Zone 1 therefore may be similar to such a habitat, which in contemporary environments,

Figure 5.20

Dovecote Palaeochannel 4 (DC4) Plant Macrofossil and Core Log Data





organic inclusions
top soil
peaty silt
peaty fine sand
clayey silt
silts & fine sand
fine & medium sand
medium sand
medium & coarse sand
coarse sand
boulder clay
laminations
wood fragments
lenses

is found in stagnant to low velocity flowing water, in oligotrophic-mesotrophic environments and hence represents the connection with the main channel, maintained following cut-off. Considering the low, but persistent, numbers of arboreal seeds in the samples, the trees may be proximal to or may line the palaeochannel, with the seeds falling or blown in.

Table 5.4 Palaeochannel DC4 Plant Macrofossil Core Log

Depth	Transition (from above)	Description	Facies Code
0-23		compression	
23-41		top soil, fine sandy clayey silt, medium brown, some mottling	P
41-55	graded	clayey silt orange brown, small amount of mottling, oxidised organics	Sh
55-60	graded	root penetration, v fine sandy silt, dark/medium brown, occasional oxidised organics, organic lens at 60cm	Sh
60-66	graded	orange/grey medium brown very fine sandy silt, freq. organics, some oxidation, fine laminations, woody organics	Sh
66-79	graded	alternate bands of (1&3) light grey brown fine sandy silt, fine laminations charcoal fragments, less structure than 2&4 more organics in 3 (2&4) fine silt small amount of very fine sand, fine laminations, some organics some oxidised material.	Sh
79-86	graded	dark/medium brown silty fine sand, finely laminated, occasional organics	Sh
86-91	graded	fine silt, very small amount of fine sand, occasional organics and charcoal, medium brown	Sh
91-98	graded	dark brown fine sandy silt, freq. organics, finely laminated	C
100-119		compression and contamination	
119-129		peaty fine sandy silt, dark brown, freq. organics, poorly humified.	C
129-159	graded	silty fine sand medium-dark brown, freq. organics, 136-138 large organic horizon, some lamination	C
159-166	graded	medium/dark brown fine silty sand slightly coarser than above, large organic lens at top, 164cm-large branch of 3cm diameter	C
167-173	graded	dark/medium grey brown, fine silt small amount of fine sand, laminated, freq. organics	C
173-176	graded	peaty fine sand, little silt, very dark brown well humified	C
176-177	sharp	very fine sandy silt, red/brown, flood horizon	
177-180	sharp	peaty silty fine sand, lots of organics, very well laminated, light brown	C
180-189	sharp	very fine silty sand, light grey brown, some organic inclusions and fragments, 186cm- medium/fine sand flood horizon of 0.3cm	Fl
189-215	sharp	medium-coarse orange brown sand, occasional organics, 193cm-fine sandy silt layer	Fl
215+	sharp	deep red boulder clay	Dmm

Macrofossil zone 1 correlates with sediment facies Fl (Table 5.4), therefore the hydrological conditions of macrofossil deposition within zone 1 are slow moving-stagnant water (Fig 5.18). The sediments suggest backwater inputs and some *in situ* organic matter accumulation with the proportion of organic matter in the sediment increasing up profile (see loss on ignition-LOI- values, Fig 5.20). The main aquatic species within the fossil record however exhibit a persistent presence implying their establishment within the palaeochannel habitat.

Conversely, a number of species were present as single seeds. *Hieracium sp.*, for example, only has a single presence and is not found in aquatic habitats (Grime *et al.* 1990), therefore is not suited to the habitat of zone 1, may have been transported prior to deposition. The sandy layer at 186cm depth is not laterally extensive and may be material from the sediment plug or an inundation event which overtopped the sediment plug. The sediment however had no visible effect on the fossil record.

Macrofossil zone 2 extending from 180 to 162cm depth (Fig 5.20) shows changes in community composition from one dominated by aquatic species to one which includes the wetland species *Carex* spp., *Epilobium palustre*, and *Filipendula ulmaria*, open water cladocera-*Daphnia*, and *Salix* spp., the latter found on exposed coarse sediment deposits (Robertson & Augspurger 1999). A high number of degraded seeds are also present. The zone comprises the lower part of the organic C facies (Table 5.4, Fig 5.18). Succeeding the community of zone 1, therefore, zone 2 comprises a persistent aquatic environment with the establishment of wetland species, signifying an increase in vegetation cover on the exposed surfaces, as also implied from the increasing organic content of the palaeochannel fills (LOI values, Fig 5.20). *Epilobium palustre* and *Salix* spp., for example, are both rapid colonists of exposed wetland surfaces (Grime *et al.* 1990, Boggs & Weaver 1994). The persistent but reduced area of standing water, is evident from the lesser numbers of *Potamogeton* spp. and continuous presence of *Daphnia* ephippia in the sediment. Zone 2 corresponds with an oxbow lake/backswamp habitat. The wetland species therefore will have established on the edges of the habitat, on the surfaces created by the deposition of the fine/medium sand facies, or during the accumulation of the organic facies.

With the exception of 176-177cm, the sedimentary characteristics of zone 2, facies C suggest a low energy environment, low sedimentation rates and predominantly autochthonous organic matter deposition. The sandy horizon at 176-177cm is thought to be either a runoff or an overbank deposit. Macrofossils within the sand layer include a large influx of *Salix* spp., with Poaceae, and *Cerastium fontanum*. The anomalous large presence of *Salix* spp. within the sandy horizon could be interpreted as the result of long distance transport. Some *Salix* spp., for example, are known to be rapid colonists of fluvial bars (Johnson & Sasser 1985) so its presence in the fossil record does not conflict with the environmental conditions represented. Furthermore, the *Salix* fragments are persistent throughout zone 2; therefore the shrub is assumed to have established in or around the palaeochannel habitat. Conversely, the Poaceae and *C. fontanum* seeds are only present in zone 2, within the sandy horizon and hence, may have been transported prior to deposition.

Assessment of published accounts of wetland vegetation communities highlights similarities between the species composition of zone 2 with the *Phragmites australis* swamp and reed bed community (Rodwell 1995). This community contains the wetland and some wide niche species of zone 2 and is commonly found wetland transitional zones, often in floodplain mires. The fossil record thus depicts the process of vegetation succession incorporating changes to the trophic status of the channel and terrestrialisation (cf. Bornette *et al.* 1994d) as the macrofossil data proceeds from the aquatic community in zone 1 to an increasing vegetation cover and floodplain mire type community of zone 2.

Zone 3 from 162-145cm depth comprises Poaceae, *Potentilla erecta*, *Cirsium* spp., bryophytes, *Carex* spp., *Juncus* spp., and *Hieracium* spp. (Fig 5.20). The species composition indicates a reduction in ponded waters with the absence of aquatic species while *Carex* spp., *Juncus* spp., *Cicuta virosa* and the bryophyte fragments represent a continuous wetland community within the palaeochannel. Facies C (Fig 5.18) corresponding with macrofossil zone 3 (Table 5.4), indicate a low sedimentation rates and autochthonous organic matter and hence macrofossil deposition. There is a distinct drop in the quantities of organic matter however within the zone (LOI values Fig 5.20) but little change in sediment size suggesting a slight reduction in vegetation cover and a possible increase in sedimentation rate from the underlying zone 2. The decline in aquatic habitat therefore appears not to have been rapidly replaced with a successional community. Reasons for the lack of change are not apparent from the macrofossil data or sedimentary conditions, as there is no evidence for desiccation or drought (cf. Bornette *et al.* 1994d), with the persistence of wetland vegetation (*Carex* spp. and bryophytes), or for disturbance. Pokorny *et al.* (2000), from vegetation reconstruction of a late Holocene floodplain mire, found increases in bryophytes to be linked to a reduction in high nutrient inputs from flood inundation, and increases in low nutrient groundwater flow. The absence of evidence for increased fluvial inputs, but persistent high water tables and increased bryophyte presence within DC4 may therefore relate to increased oligotrophic groundwater inputs (Chapter 7, Section 7.2.2).

At 156cm depth there is an anomalous high number of *Cicuta virosa* seeds. The contemporary population of *C. virosa* is sparse in comparison to its former abundance, and in northern Britain is presently confined to south west Scotland and Northumberland (Perring & Walters 1976, Halliday 1997). As the decline of the species occurred after the 1950s (Rodwell 1995) its present distribution will not be the same as that 400 years ago, when the

palaeochannel was abandoned. *C. virosa* is found is primary fen communities (Pokorny *et al.* 2000) which links it with the other species niches within the macrofossil zone.

Zone 4 of DC4, lies between 145 and 115cm depth (Fig 5.20), and displays a marked change in the composition of macrofossil species, which include *Salix* spp., *Daphnia* ephippia, and *Carex* spp. (in lower numbers). *Tragopogon pratensis, Arenaria* spp., *Cerastium fontanum, Anthemis* spp. and *Euphorbia cf. helioscopoia*, are also present, all of which are characteristic of disturbed habitats, and waste ground (Stace 1997). This establishment of ruderal species and return of aquatic biota suggests a change in palaeochannel habitat conditions. The reduction in numbers of both wetland seeds and species indicates a cessation in the development of the wetland habitat, established within the temporal sequence of zones 1-3, with return of *Daphnia* ephippia implying an increase in wetness or a re-establishment of ponded water (Birks 2000). The macrofossil core for DC4 at this level corresponds with facies C and shows the presence of an organic debris layer between 136-138cm (Fig 5.20, Table 5.4). The associated downstream peaty fine sand facies contain two major palaeoflood horizons, the lower of which corresponds with the initial macrofossil change, with the upper corresponding with the top of zone 4 (Fig 5.19). Based on stratigraphic evidence from the downstream section of the palaeochannel, the marked change in the macrofossil data appears to correspond to flood inundation and deposition. Although more accurate dating is required to connect the upstream and downstream deposits of DC4, the debris layer within the macrofossil core at a stratigraphically comparable level with the flood horizons downstream, could be interpreted as a strandline deposit. The presence of ruderals and aquatics may have arrived *via* flood waters, or rapid establishment on newly formed exposed areas, and ponded waters. Towards the top of the zone there is a reduction in *Daphnia* and a slight increase in wetland species, including *Epilobium palustre, Juncus* spp., *Carex* spp., and *Callitriche* spp. indicating a further expansion of the wetland habitat and a partial recovery following flood disturbance.

The uppermost section of DC4, zone 5, beginning at 115cm and continuing to the top of the fossil record (Fig 5.20), terminates due to aerobic conditions at the top of the core degrading organic matter and preventing plant macrofossil preservation. The species composition of this zone includes wetland species *Lycopus europaeus, Glyceria fluitans, Filipendula ulmaria, Carex* spp., *Sparganium* spp, and *Silene dioica*. Also present were *Potentilla erecta*, a species requiring high moisture edaphic conditions, and *Rumex* spp., *Ranunculus* spp. and *Senecio* spp, all of which have wide habitat niches. The bottom part of zone 5 signifies the limit of *Betula pubescens* within the core, although *Alnus glutinosa* is persistent (Fig 5.20). The most

recent part of the macrofossil record, therefore, indicates a more diverse habitat than zone 4 but with a lower concentration of plant macrofossils. The fossil community typifies a wetland environment, with all of the species also found in contemporary *Phragmites australis* swamp and reed bed communities (Rodwell 1995), commonly found as part of the zonation between open water and floodplain mire environments. The low numbers of macrofossils, however, could be linked to a more sparse vegetation cover. Sediments corresponding with zone 5 comprise the upper part of C facies grading into Sh facies (Table 5.4, Fig 5.18), with reduced organic inclusions (LOI values, Fig 5.20) and persistent fine sand laminations, constituting a change in environmental conditions. Increased fluvial inputs and sedimentation rate may explain the reduction in macrofossil preservation and vegetation cover, with an increasingly permeable substrate resulting in the degradation or oxidisation of organic material although the presence of wetland species depicts periodic waterlogging.

Zone 5 contains species which are constituents of Peucedano-Phragmitetum australis wetland communities, as defined by Rodwell (1995). Within the published wetland communities, however, are dominant tall herb fen species, which are absent in the fossil record. The absence of such species such as *Phragmites australis*, may be the result of limited seed production (Grime *et al.* 1990) and the fragile nature of the seeds from plants of the Poaceae family. Activities including mowing reeds and sedge and grazing also affect the composition of wetland communities (Rodwell 1995). The contemporary palaeochannel is subject to grazing and mowing which results in a thin cover of grasses and wetland species. Overall therefore the uppermost macrofossil zone of DC4 appears to reflect the present palaeochannel habitat characteristics.

From the bottom of the core up-profile there is a consistent presence of arboreal species in the macrofossil record (Fig 5.20). As discussed above, *Salix* spp. may have established on the exposed surfaces of the palaeochannel, whereas *Alnus glutinosa* and *Betula pubescens* may have lined the former channel or occurred proximal to it. Both species are frequently found on damp valley floors and along river banks (Grime *et al.* 1990). The absence of woody fragments in the macrofossil core and sediments and lack of evidence for root penetration in the sedimentary data (cf. Brown & Keough 1992) adds to the argument that the species were not growing on the palaeochannel surface, but were nearby. The presence of *A. glutinosa* and *B. pubescens,* therefore, is not a direct result of biotic development within the palaeochannel.

5.4 Results and Analysis for Palaeochannel DC7

Palaeochannel DC7, associated with terrace T7 (Fig 5.1) is a low sinuosity former meander bend (Fig 5.1), abandoned between 1771 and 1882 (Section 5.1.1). An 80m section of the palaeochannel, located downstream of a small alder woodland (Plate 5.5) was selected for detailed sedimentological and plant macrofossil analysis. The fill sediments of the palaeochannel can be seen from an exposed floodplain section (Plate 5.2).

5.4.1 Palaeochannel geometry

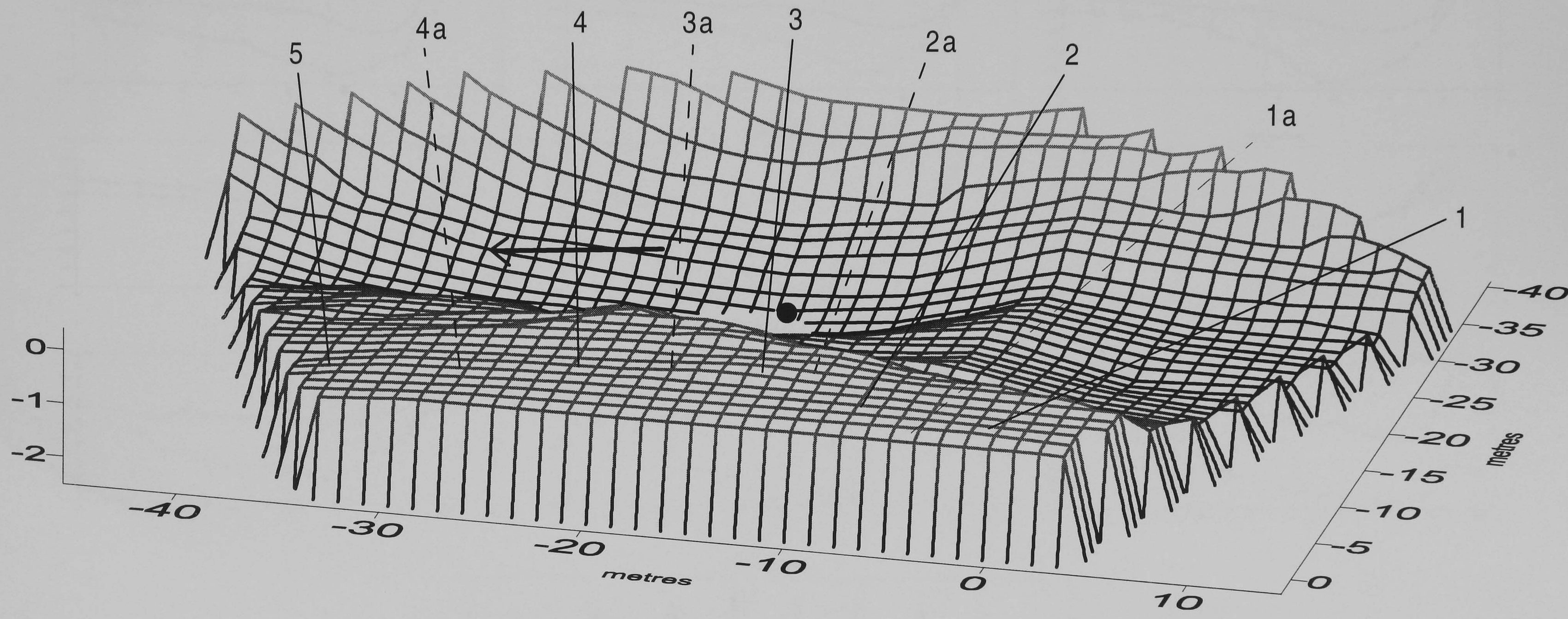
Nine transects along palaeochannel DC7 were cored at 2m intervals and at higher resolutions to ascertain change of slope if required. Every core location was surveyed (Fig 5.22). Sediments were logged for the cores extracted along transects 1 to 5 (Fig 5.23). Depth of palaeochannel fill was recorded for the cores taken along transects 1a to 4a.

The three dimensional reconstruction of the former gravel surface of DC7, associated with terrace T7 (Fig 5.1), reveals a curved section of palaeochannel (Fig 5.21). With the exception of transect 5, the former channel bed has well defined right bank slopes and lower gradient slopes on the left channel side. From the cross section profiles (Fig 5.22) there is a morphological transition from the wider shallow transects 1 and 1a, through to transects 2a and 3 which are the deepest of the whole reach. Further downstream, there is a shallowing of the channel from transect 3a to 5. Each profile displays an asymmetrical form, although, the deeper channel profiles are more symmetrical than their shallower counterparts. Transect 5 has a poorly defined right bank side, with only a small rise in the gravel surface followed by a drop in elevation (Fig 5.22).

The reconstructed gravel bed morphology of palaeochannel DC7 reveals a section of a meander bend. From cartographic evidence it is known that the form of channel abandonment was through the abandonment of a meander bend during the late 18th to early 19th century (Section 5.1.1). The gradient of the outer banks is high indicative of lateral erosion. However, the gradients of the outer banks of DC7 are lower than palaeochannel DC4 (Fig 5.16), suggesting either a lesser magnitude of lateral erosion or a slumping of the gravel banks The low gradient of the inner banks of the meander at the downstream end (transects 3a to 5, Fig 5.22), infer the presence of a former point bar. The overall morphology of the channel is representative of a former riffle-pool-riffle sequence.

Figure 5.21

Dovecote Palaeochannel 7 (DC7) Gravel Surface Morphology



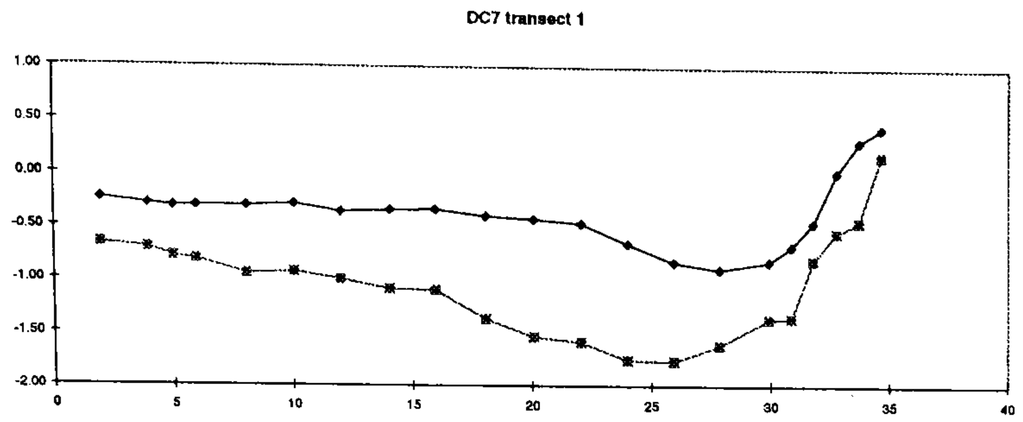
● Plant macrofossil core location

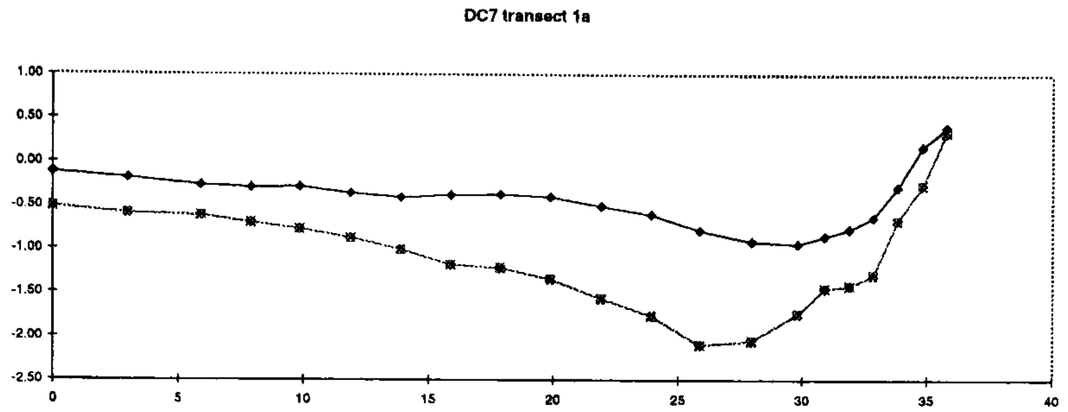
——— Transects with detailed sedimentary records

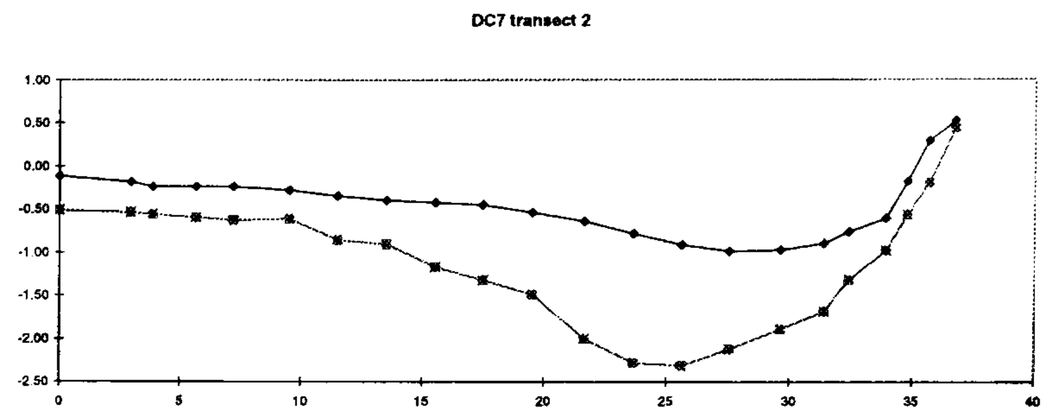
– – – Transects recording depth to gravel

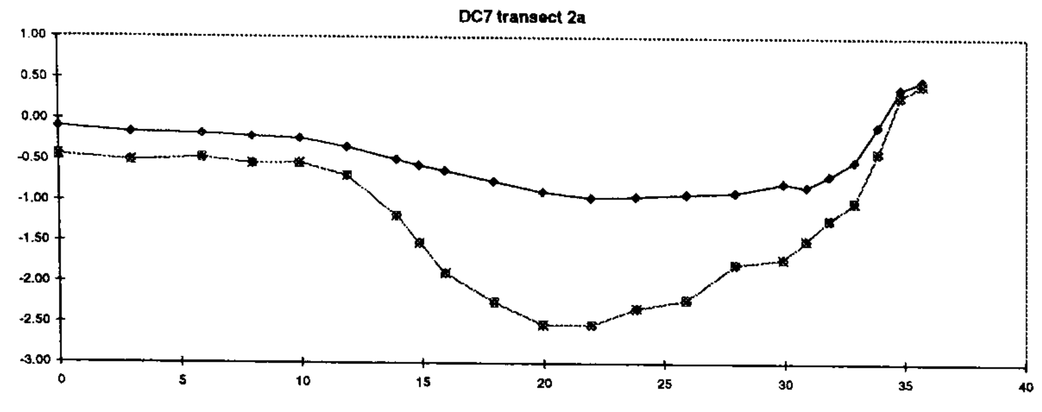
Dovecote Palaeochannel 7 (DC7) Gravel Surface Cross Section Profiles

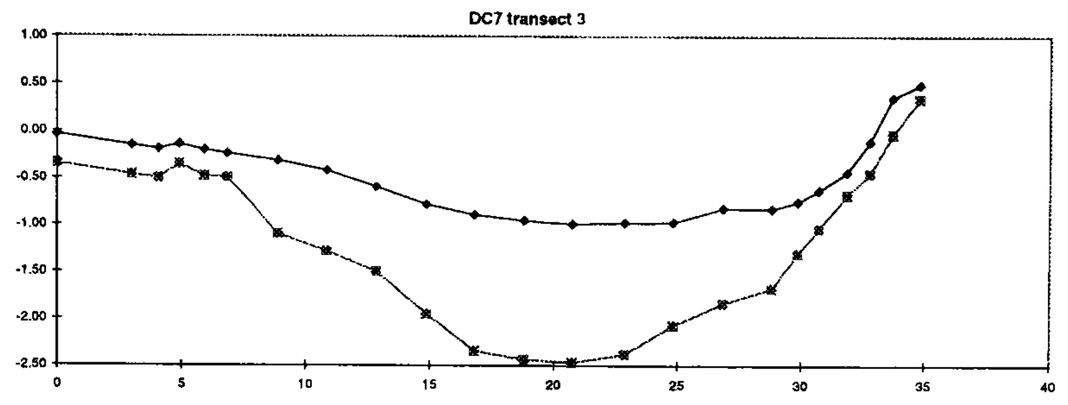
Figure 5.22

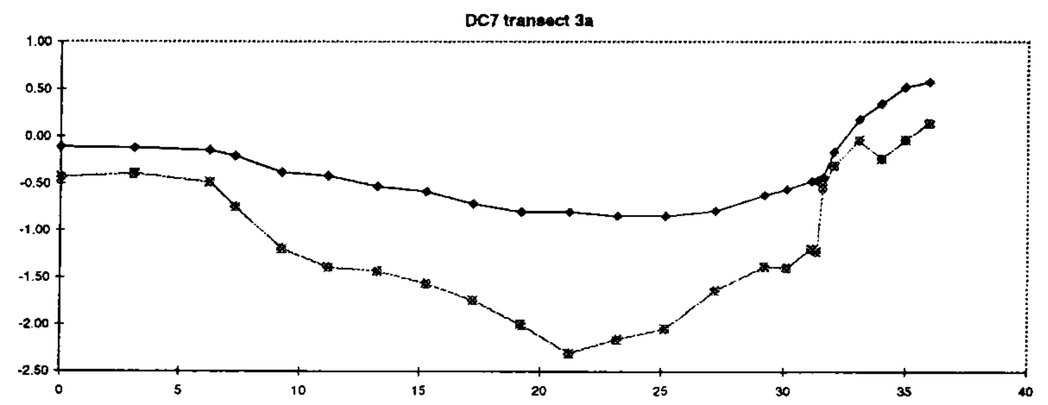


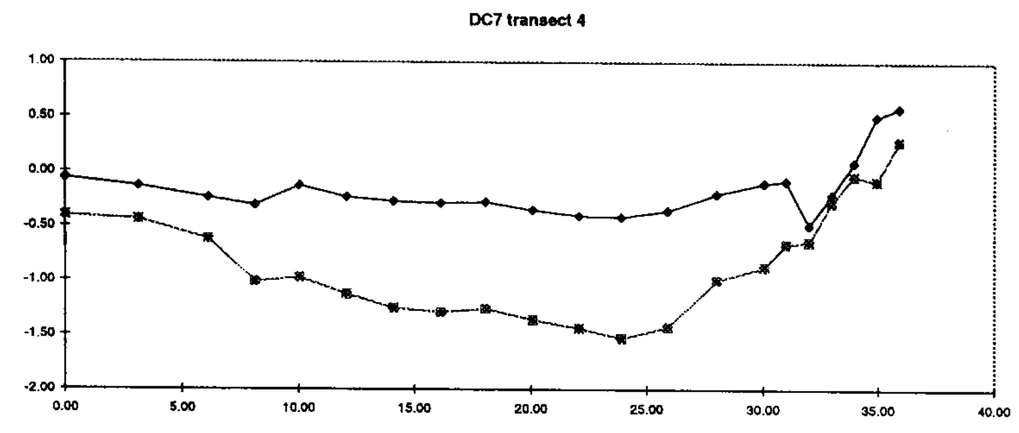


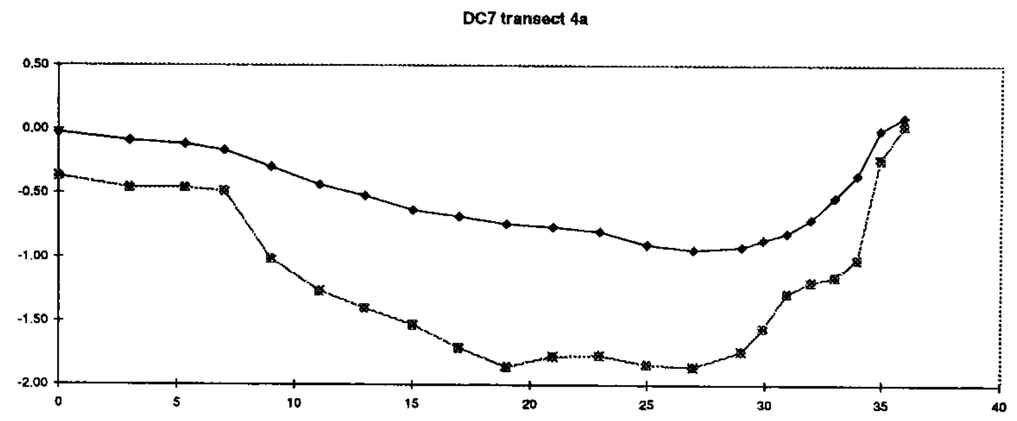


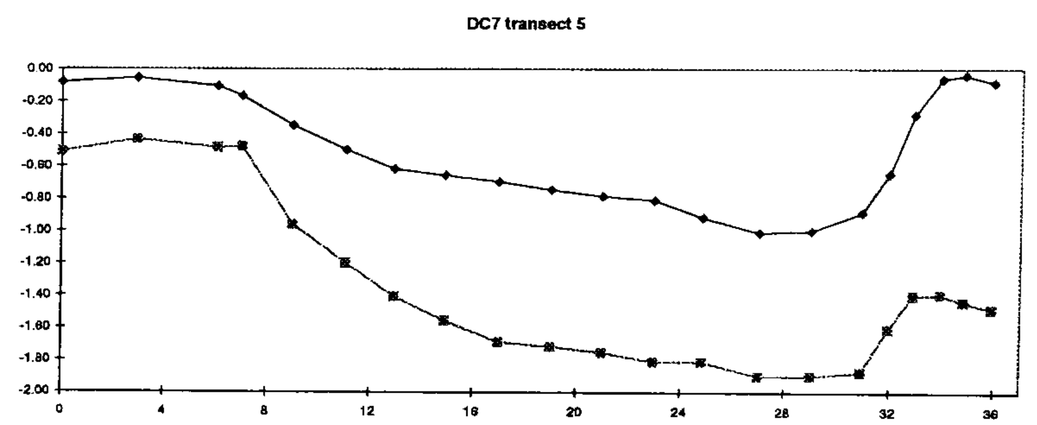


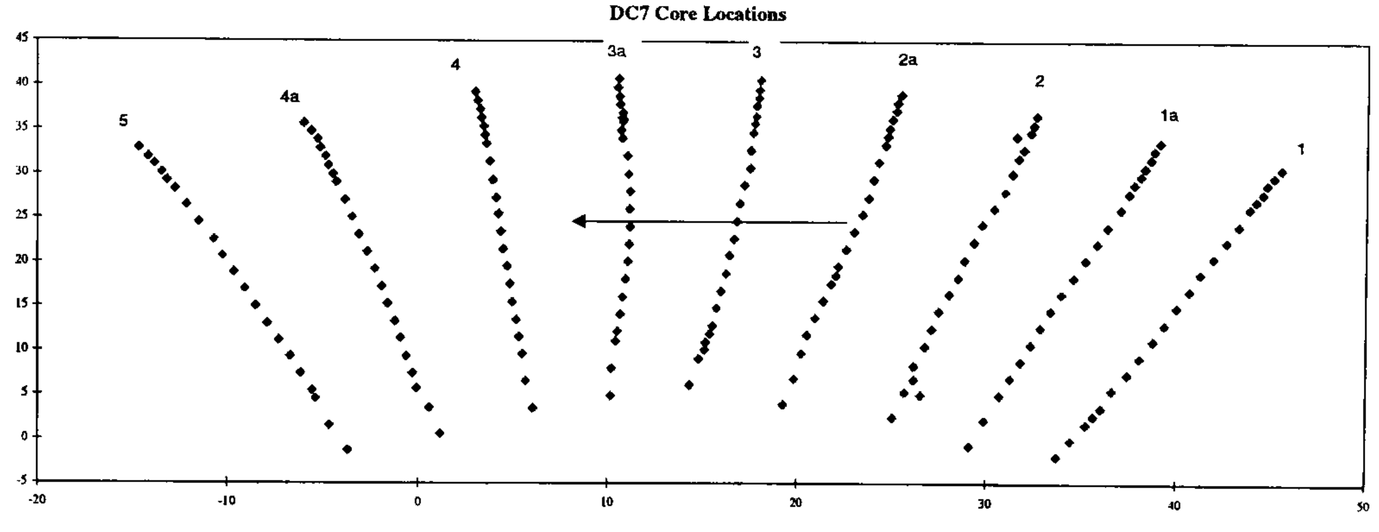












The location of transect 5 is at the mouth of the cut off point of an older terrace and palaeochannel unit (T5-Fig 5.1), known to contain up to 1.5m of organic sediments (Fig 5.23). The older channel surface is reflected in the poorly defined gravel surface morphology of the right bank of transect 5 as the gravel slope only rises to the level of the bed height of the older river channel (Fig 5.22). The difference in gravel bed surface between the older palaeochannel and DC7 is approximately 0.5m.

5.4.2 Lithostratigraphy of channel fills in palaeochannel DC7

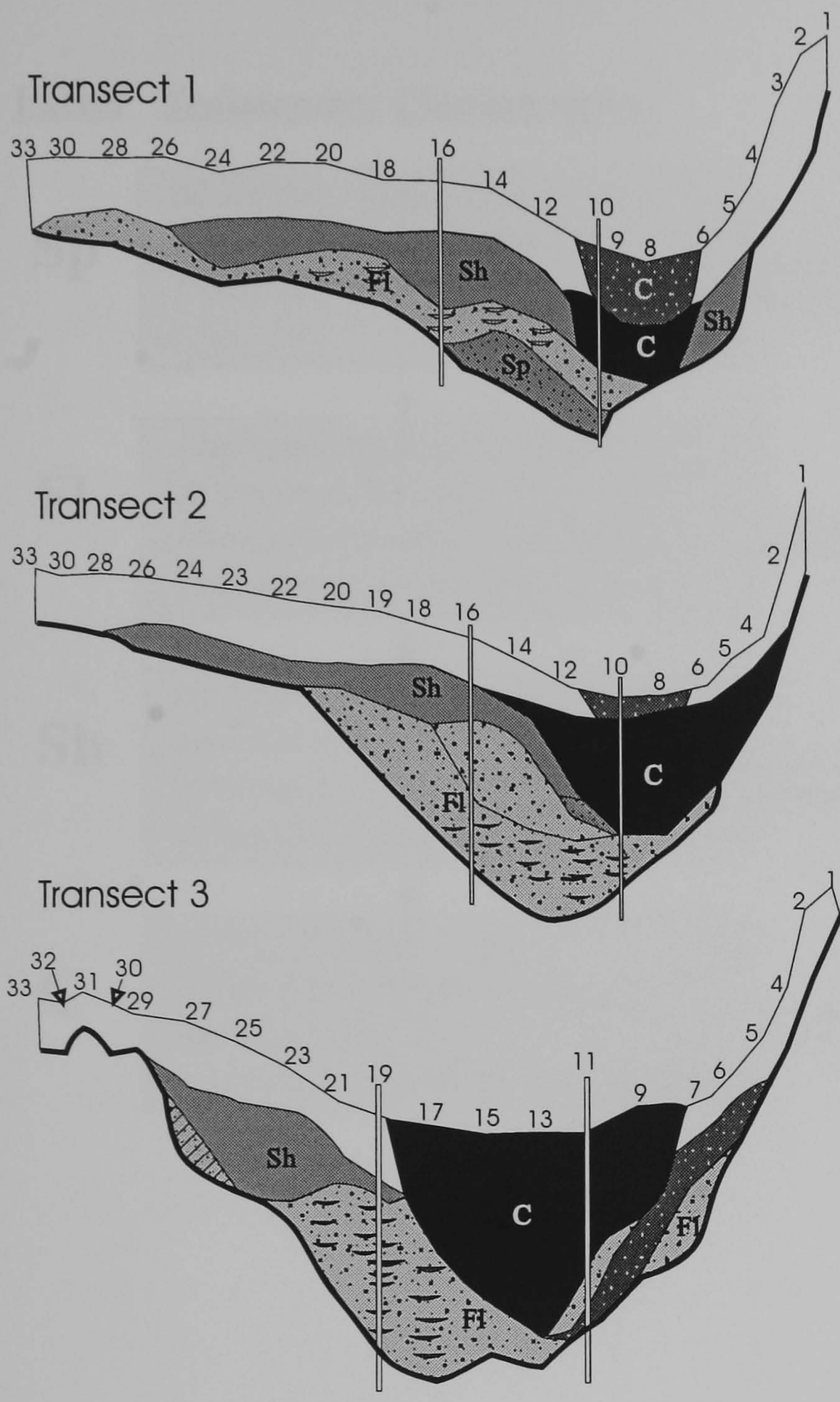
The results for the sediment coring of DC7 are represented in Figure 5.23 with transect 1 located at the upstream end of the palaeochannel reach, and transect 5 at the downstream end. Using the lithofacies classification (Table 4.2) the sediments within the fine grained palaeochannel fill of DC7 have been divided into facies representing specific depositional environments. Each facies is described and discussed below while the temporal sequence of palaeochannel infilling is shown in Fig 5.24.

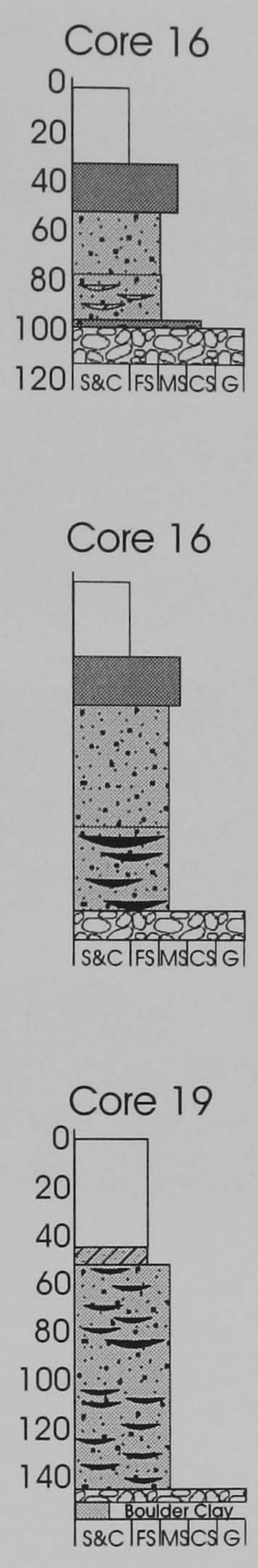
The exposed cross section of palaeochannel DC7 (Plate 5.2) shows how the channel is set into coarse sands and gravels (Table 5.2). The majority of the cores taken along the nine transects recorded fine grained palaeochannel fill sediments to basal gravels. A small number of deep cores, however (e.g. Core 19 Transect 3 Fig 5.23), revealed fine organic fill sediments overlying a thin coarse sand layer, below which was a clean pink clay (Plate 5.6), similar to that found below basal sediments in palaeochannel DC4 (Section 5.1). The clay is interpreted as a possible glacio-lacustrine deposit.

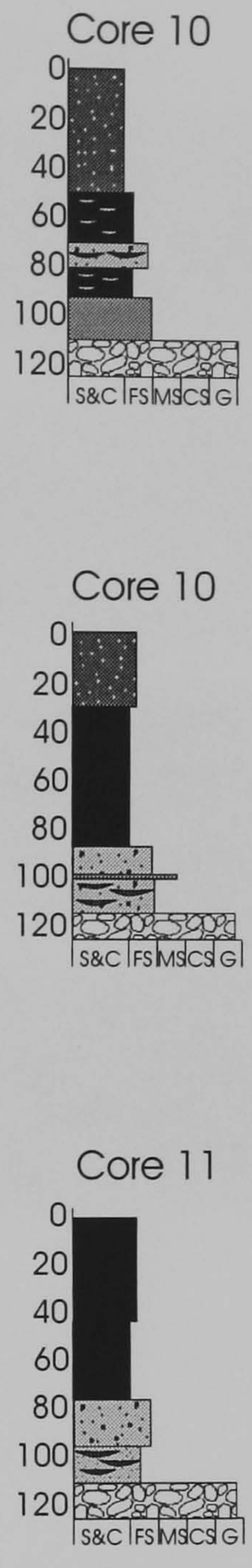
Overlying the gravel and clay surface towards the centre of the palaeochannel in transects 1 and 4 are infill sediments comprising medium sand (e.g. Core 10 Transect 1-Fig 5.23) and medium/coarse sand (e.g. Core 18 Transect 4-Fig 5.23). This spatially discontinuous deposit forms a medium/coarse sand facies Sp, the oldest channel fill deposit in DC7, deposited after channel abandonment between 1771 and 1822. As the sediments have been deposited on the base of the channel as opposed to the point bar, where no evidence for lateral accretion sediments can be seen, the facies represents the bed load of the river. Sediments were deposited during low flow conditions or during the period of channel abandonment with the

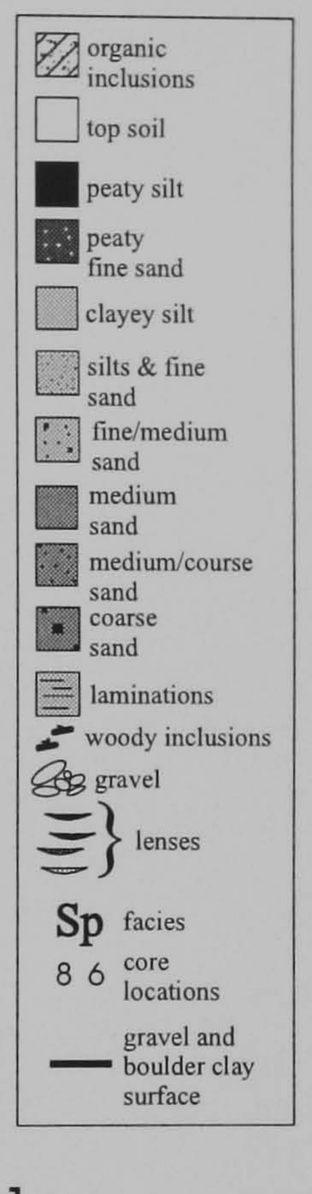
Figure 5.23

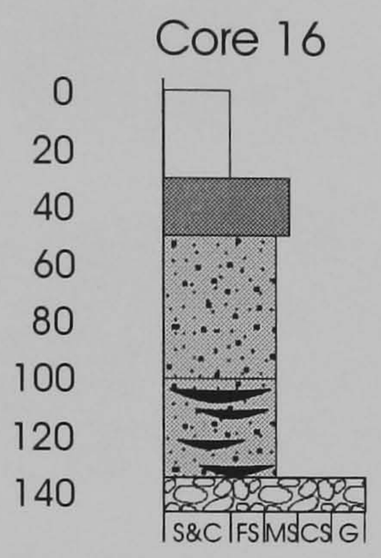
Dovecote Palaeochannel 7 (DC7) Sedimentary Infills

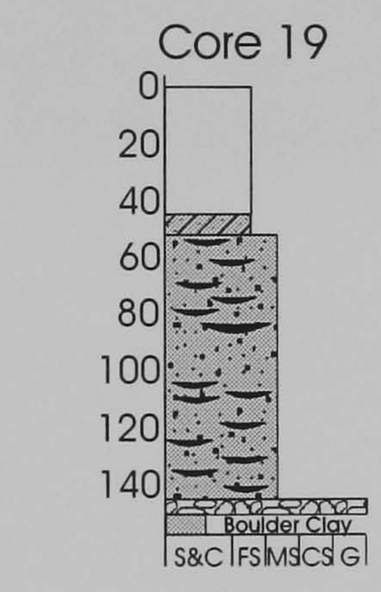


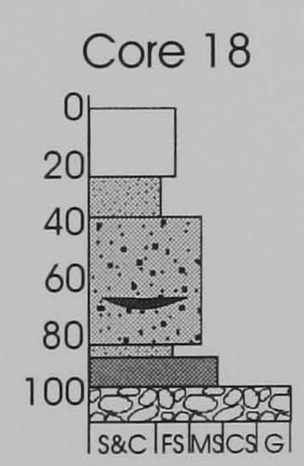


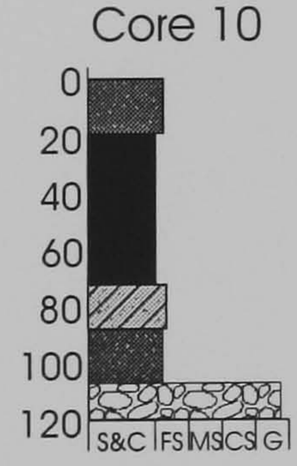


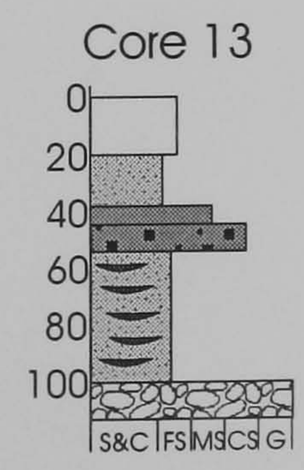


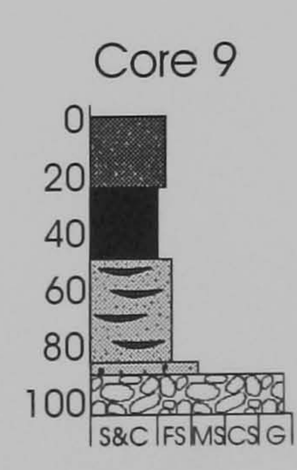






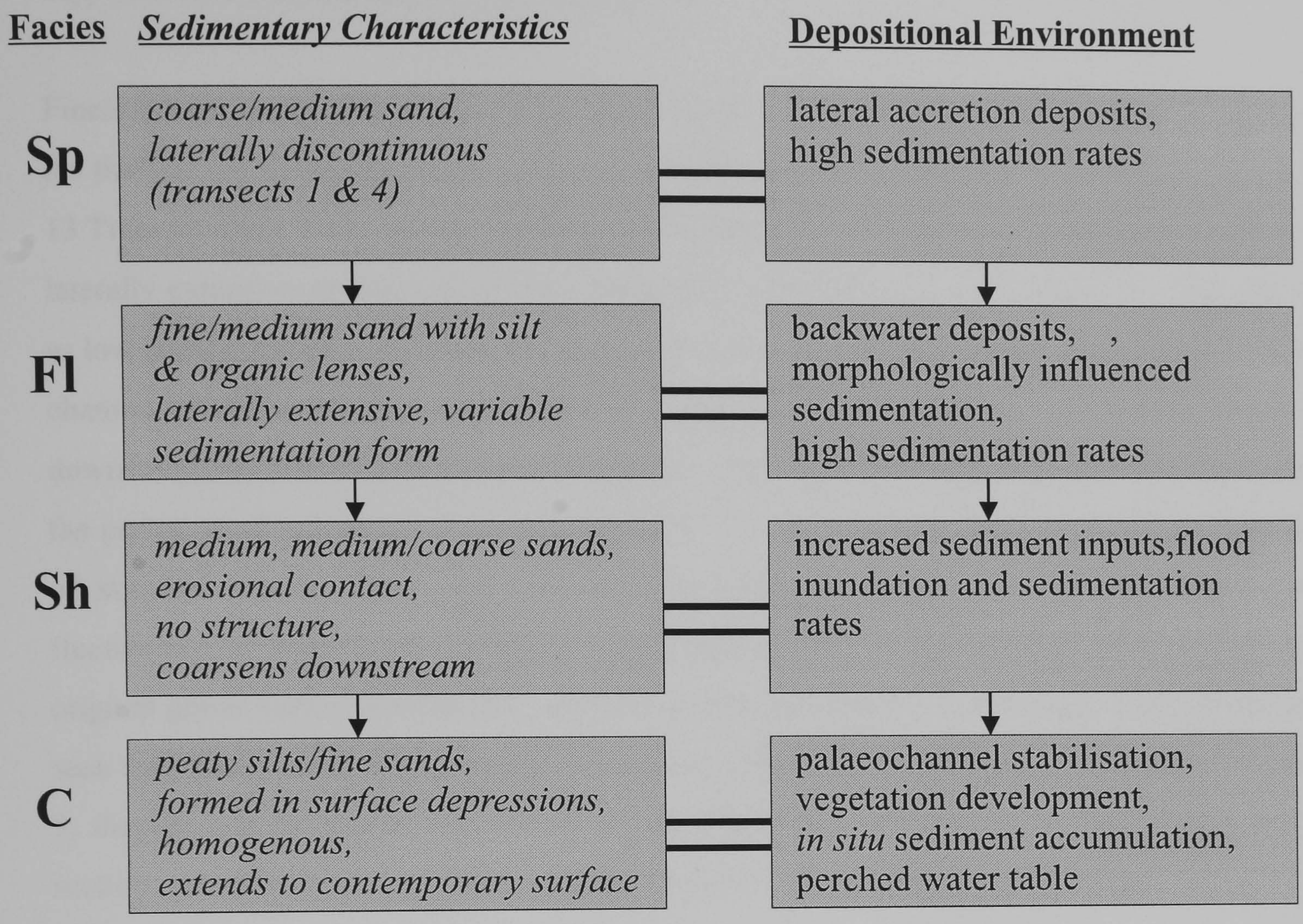






DC7 - Model of Sedimentary Deposition

Figure 5.24



spatial discontinuity in sedimentation reflecting either variable flow velocities during deposition or their subsequent erosion and scour.

Fine/medium sands with silt and fine sandy organic lenses form horizontal deposits across the transect overlying the gravel surface of transects 2, 3 and 5 (e.g. Core 19 Transect 3, Core 13 Transect 5-Fig 5.23) and the Sp facies of transect 1 and 4 (e.g. Core 16 Transect 1). These laterally extensive deposits have been grouped as a fine/medium sand facies, Fl, interpreted as low energy, backwater sediments, deposited during the period of connection with the main channel following abandonment (fig 5.24). From cartographic evidence it is known that the downstream section of palaeochannel remained connected to the main channel in 1822, with the period of abandonment occurring between 1771 and 1822 (Section 5.1.1). The presence of silt and organic lenses indicates the inwashing of organic material and occasional fluctuations in water level, sediment supply and sedimentation rate. The influence of the original gravel surface morphology and flow within the channel on alluviation patterns can be seen from the channel fill sediments. The former riffle sections of channel, transects 1, 4 and 5, display a horizontal sedimentation pattern (Fig 5.23), whereas the former deeper pool section, transects 2, and 3, display an inclined sedimentation pattern (Jones 1999).

Within all of the palaeochannel transects medium and coarse/medium sands (e.g. Core 16 Transect 1, Core 16 Transect 2-Fig 5.23) with lower erosional contacts have accumulated above facies Fl. The sediments form a medium and fine-medium sand facies, Sh. The erosional surface and increase in grain size of the facies, compared to the underlying backwater sediments, indicate an increase in sedimentation rate and higher flood magnitude inundation with possible increases in sediment supply, as seen by Erskine *et al.* (1992) on the River Hunter, Australia. Facies Sh is laterally extensive across the palaeochannel, although less apparent across transect 4 (Fig 5.23). As with the backwater sediments, spatial variability of sedimentation exists due to the morphological template provided by underlying facies. The persistence of a channel form within the palaeochannel fill sediments suggests flow through the palaeochannel that has scoured some of the underlying sediments.

Overlying the Fl and Sh facies, accumulating in the channel-like depressions formed by the infill sediments, are peaty silts and peaty fine sands (Fig 5.23) which comprise facies C. The increase in organic content and decrease in sediment grain size render the facies distinct from the lower sediments and suggest a de-coupling of the palaeochannel from the main channel. The increasing organic content of the sediments (see LOI values-Fig 5.25) indicate a reduction in sedimentation rate, increases in autochthonous organic matter accumulation and

hence, an increase in vegetation cover. The sedimentation pattern of facies C is partly determined by the depressions formed by the underlying sedimentation patterns, while its extension to the present surface is enabled by a perched high water table resulting from the organic content of the palaeochannel fill (Brown 1997a) and the proximity of the palaeochannel to the active River Irthing channel (Fig 5.1).

5.4.3 Plant macrofossils

A 145cm deep core was extracted from palaeochannel DC7 (Fig 5.21) for plant macrofossils analysis. The whole core was sampled at 2cm intervals for both plant macrofossil analysis and loss on ignition (LOI) values. The results of the plant macrofossil analysis have been divided into six zones according to species present and changes in fossil community composition (Fig 5.25) in order to describe and discuss the changing composition of the fossil record.

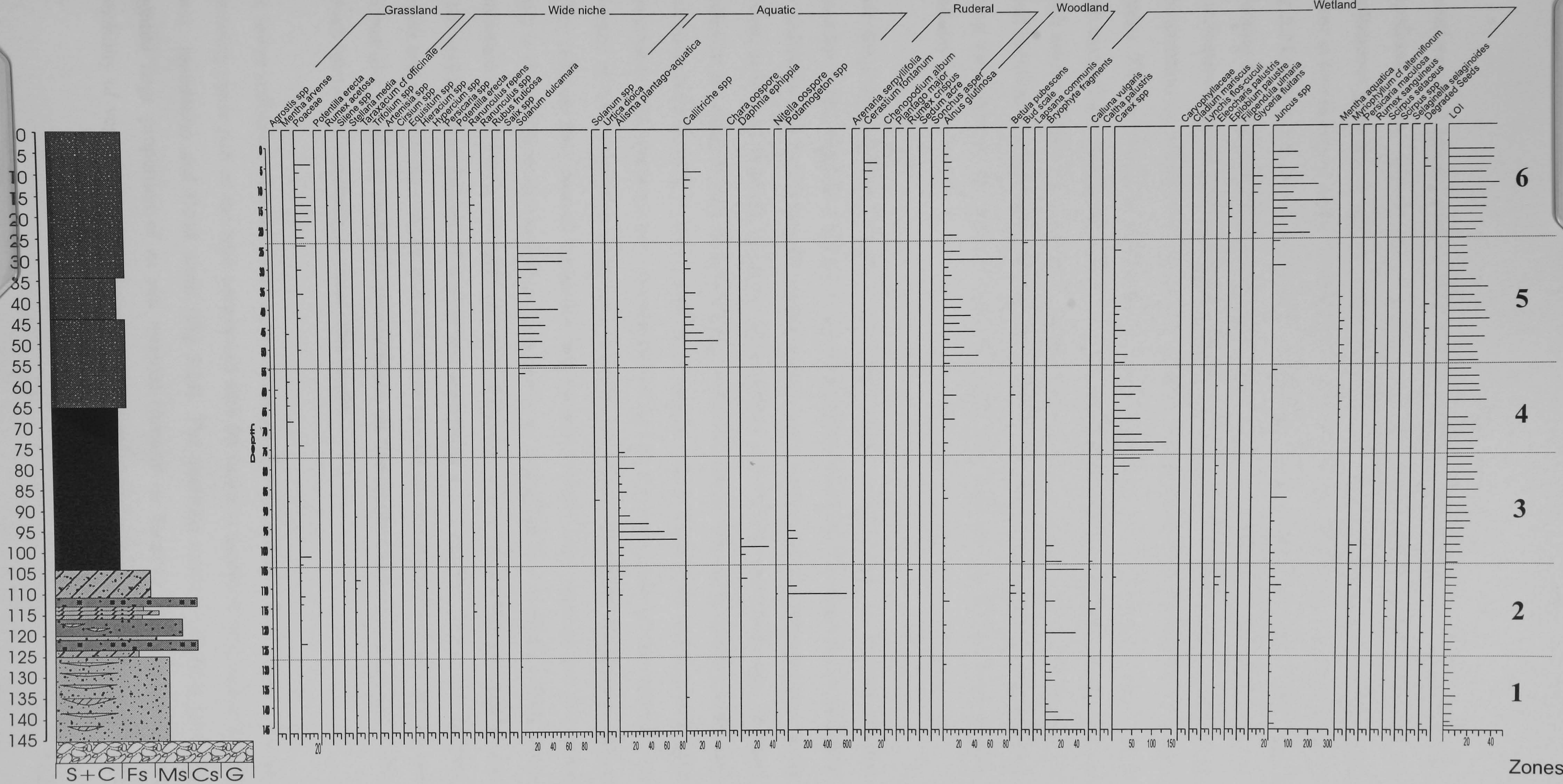
Table 5.5 Palaeochannel DC7 Plant Macrofossil Core Log

Depth	Transition (from above)	Description	Facies Code
0-34		medium grey brown peaty silty top soil, large root content, whole organic inclusions, friable near surface	C
34-44	graded	light grey brown peaty silt, large reed inclusions, some humified organics matter at 44cm, little structure	C
44-65	graded	light grey brown organic peaty silt, very small amount of fine sand, some organic inclusions, little structure	C
65-104	graded	light yellow/grey/brown peaty silt, lots of organic inclusions, little structure, changing organic content seen in colour changes	C
104-111	sharp	medium brow organic silty medium fine sand, few organic inclusions	Fl
111-113	sharp	orange brown coarse medium sand	Fl
113-114	sharp	organic silty medium fine sand, some organic inclusions	Fl
114-115	sharp	organic fine medium sand	Fl
115-116	sharp	organic silty medium fine sand, some organic inclusions	Fl
116-120	sharp	orange brown coarse medium sand, 0.3cm layer of organics at 117cm, occasional organic silty fine sand layers	Fl
120-121	sharp	dark/medium brown silty medium fine sand	Fl
121-123	sharp	orange dark brown medium coarse sand	Fl
123-125	sharp	dark medium brown silty fine sand, few organic inclusions	Fl
125-145	sharp	medium brown, fine medium sand, occasional silty fine sand organic lenses, organic lenses at 135-138 and 142-143	Fl
145+	sharp	gravel	Gm

At the bottom of the core, zone 1 extends from 145 to 127cm depth and contains a low number of plant macrofossils (Fig 5.25). Those macrofossils present include bryophyte fragments and small numbers of aquatic species such as *Chara* spp., *Potamogeton* spp. and

Figure 5.25

Dovecote Palaeochannel 7 (DC7) Plant Macrofossil Data



ruderal/grassland species such as *Cerastium fontanum* and *Stellaria media* (Fig 5.25). The macrofossil record appears not to reflect a specific vegetation community due to the simultaneous presence of species from with different habitat preferences, all of which are present in low numbers. Zone 1 corresponds with the lower section of the backwater facies Fl (Fig 5.24, Table 5.5) which, as the core sediments show, consist of a range of grain sizes reflecting temporal variability in sediment supply and flow velocities. The low numbers of macrofossils therefore infer a limited vegetation cover, exposed surfaces and potentially high sedimentation rates with, consequently, unsuitable conditions for the preservation of organic remains. The dominance of fluvial inputs suggest the presence of reworked or long-distance plant macrofossil deposition, which is also indicated by the macrofossil species present which are not found in riverine or floodplain wetland sites. *Calluna vulgaris,* for example, is found in heaths and moorland habitats (Stace 1997), abundant in the upper parts of the River Irthing catchment at the period when DC7 was abandoned during the late 18th century (Halliday 1997).

Macrofossil zone 2 extends from 127 to 104cm depth, contains a greater number of seeds than zone 1 and suggests a change in environmental conditions. The macrofossil species in the sediments are predominantly aquatics with large numbers of *Potamogeton* spp. seeds present, as well as *Daphnia* ephippia, *Myriophyllum alterniflorum* and *Chara* spp.. Wetland species in the fossil record include *Scirpus setaceus, Juncus* spp., *Eleocharis palustre*, and *Epilobium palustre* (Fig 5.25). A number of ruderal, arboreal and wide niche species were also present. The composition of the macrofossil record, therefore, indicates the synchronous presence of two vegetation communities within the palaeochannel as the species habitat niches fall into two distinct categories; aquatic and wetland. The aquatic species present typify a *Potamogeton-Myriophyllum* community as exemplified by Rodwell (1995). Such communities are found in the north and west of Britain, in slow-deep water, on mineral beds in the middle-lower reaches of a river and possessing a low nutrient status. The wetland species and some of the ruderals and wide niche species of zone 2 are found in water margin communities located in unshaded environments, on fine-medium sediments (Rodwell 1995) and are tolerant of variability in water table height.

The lower sediments of macrofossil zone 2 correspond with facies Fl (Table 5.5), while the remaining upper part of the zone correspond with Sh facies, a period of increased sediment inputs, inundation and flood scour (Fig 5.24). The resulting effects will have been the potential large proportion of *ex situ* material (Amoros & Bornette 1999) and a reduced probability of vegetation establishment in the palaeochannel due to high energy conditions

and scour. From the sediment coring, it is known that the Sh facies are laterally extensive through DC7 and contain few organic lenses or inclusions (Fig 5.23). Areas around the palaeochannel may have experienced vegetation establishment; however, the sedimentary data provides little indication as to the extent of vegetation development. Although the species found in macrofossil zone 2 are common in aquatic and wetland floodplain habitats the data may reflect the input of *ex situ* material from upstream riverine and wetland habitats, although it is accepted that some seeds may derive from *in situ* resistant species.

Zone 3 spans from 104 to 77cm depth (Fig 5.25). Plant macrofossil species present include the aquatic species *Alisma plantago-aquatica*, with wetland species *Juncus* spp., *Scirpus setaceus*, *Solanum* spp. and *Glyceria fluitans* and wide niche species *Ranunculus repens* and *Stellaria media* also present (Fig 5.25). In the lower part of the zone (from 104-97cm depth) macrofossil data includes the aquatic species *Potamogeton* spp., *Myriophyllum alterniflorum*, and *Daphnia* ephippia, signifying the presence of an aquatic community. These species were also present in zone 2, but were potentially of extra-local origin. The sedimentary conditions within zone 3 differ significantly to the lower stratigraphy as zone 3 lies within organic C facies, the period of low sedimentation rates and autochthonous organic matter accumulation (Fig 5.24). The progressive increase in organic matter is reflected by the loss on ignition values for the macrofossil core (Fig 5.25). The macrofossils, therefore, will have been deposited *in situ*, and represent the rapid establishment of an aquatic community once conditions were suitable (Watts 1978, Van der Valk 1981).

Subsequent to the aquatic species in zone 3 is the emergent species *Alisma plantago-aquatica* alongside smaller numbers of wetland, wide niche and grassland communities. The lower numbers of aquatic seeds may imply a drop in water depth or terrestrialisation and subsequent reduction in the aquatic habitat of the palaeochannel. However, the variability in seed numbers present may be the result of changes in seed production following alterations to palaeochannel environmental conditions (Harper *et al.* 1970). *A. plantago-aquatica* is an emergent that is known to slowly establish itself in *Potamogeton-Myriophyllum* communities when increases in nutrient content enable it to thrive (Rodwell 1995). Increases in nutrient content of the palaeochannel are evident from the higher volume of organic material in the sediments (Fig 5.25) and will have been augmented by nutrient input from backwater inputs (Bornette *et al.* 1998a). The decline of *Myriophyllum alterniflorum*, a species found in nutrient poor environments (Halliday 1997), therefore may be connected with the change in palaeochannel nutrient status.

The combined macrofossil and sedimentary data of zone 3 indicate an aquatic-wetland habitat and the autogenic development of vegetation communities within the palaeochannel, as a result of reduced flood influence and increases in organic matter accumulation. The subsequent changes to community composition were incurred in part due to changes in the trophic status of the cut-off habitat and the reduced fluvial inputs, signifying the process of hydroseral vegetation succession (Bornette *et al.* 1994d).

Zone 4 of palaeochannel DC7 extends from 77-55cm depth, comprises facies C and displays a significant increase in species diversity and habitat characteristics. The zone is dominated by *Carex* spp., with other wetland species *Mentha aquatica, Rumex sanguineus*, and *Eleocharis palustre* present (Fig 5.25). Grassland species were found in small numbers in the core with an increase in *Alnus glutinosa* also evident. Zone 4, therefore, contains plant macrofossils whose habitat niche data are interpreted as reflecting a species poor sedge swamp environment, as the decline of aquatic species relates to reduced ponding and aquatic habitat within DC7. Such swamp communities often possess low diversity and are dominated by few species (Rodwell 1995), as indicated from the high proportions of *Carex* spp. in the DC7 core (Fig 5.25) compared with those of other species. Low levels of diversity can be the consequence of aggressive dominant species or the lack of propagule input (*via* overbank sedimentation) which may introduce new species (Bornette *et al.* 1998a). The sedimentary environment of macrofossil zone 4 reflects predominantly *in situ* organic matter accumulation and limited fluvial inputs from the active channel. The environmental conditions are similar to those found in the Grand Gravier palaeochannel by Bornette *et al.* (1998a), which had been disconnected from the main channel for up to 400 years. The diversity of the Grand Gravier was higher than that evident within DC7 due to low nutrient ground water inputs, which maintained a persistent heterogeneity of environmental conditions within the channel. Conversely zone 4 reflects undisturbed autogenic vegetation succession and terrestrialisation. The grassland species within zone 4 are not found in waterlogged environments, therefore may have been transported prior to deposition and it is assumed that these seeds were blown in from nearby sources. The grasses may have comprised, for example, the communities of the terrace bluff above DC7 and the terrace unit T7 associated with it.

Between 57 and 25cm depth, zone 5 displays a slight increase in the number of species within the fossil record, as well as a change in the environmental conditions inferred by the species habitat niches (Fig 5.25). Three species dominate the zone; *Solanum dulcamara, Callitriche* spp. and *Alnus glutinosa*. Several other wetland species and a small number of grasses are

also present. The number of *Carex* spp. gradually decreases up the core to the top of zone 5. The composition of macrofossil zone 5 signifies the development of an alder carr within palaeochannel DC7. Alder carr communities comprise *A. glutinosa* with *Carex* spp and *Solanum dulcamara* often abundant within the sub-community (Lambert 1951, Rodwell 1991). The fossil community of DC7 thus matches the composition of modern alder carr communities, which are found on waterlogged organic soils and are commonly a 'natural' successional community after swamp carr in floodplain mires (Rodwell 1991). Moreover, the increase in *Alnus* seeds corresponds with the presence of *Rumex sanguineus* and *Filipendula ulmaria*, both shade tolerant species (Grime *et al.* 1990). Lambert (1951) found the rapid colonisation of alder in fen habitats was enabled by the presence of sedge species which provided a dry 'foothold' for expansion. The presence of *A. glutinosa* stands within DC7 however was not spatially extensive during zone 5, as there is no evidence for subsidence or root penetration within the sedimentary data although it is though that alder roots can decay rapidly (Lambert & Jennings 1951).

The sediments of zone 5 comprise the peaty C facies, however the macrofossil core shows a slight increase in sediment grain size (Table 5.5), while loss on ignition values reveal a lowering of organic matter between 30 and 25cm depth. This could indicate increased overbank sedimentation, runoff, drainage or groundwater seepage. In addition, the combined persistence of *Mentha aquatica*, a species which thrives on groundwater inputs and areas where a degree of soil infertility exists (Grime *et al.* 1990, Bornette *et al.* 1998b), *Callitriche* spp., a genus found in waterlogged habitats (Halliday 1997), and return of *A. plantago-aquatica*, a high nutrient status aquatic species, suggest variability in the hydrological characteristics of the palaeochannel. In the absence of sediment laminations or sharp transitions between sedimentary horizons, it is assumed that hydrological change, and a consequent change in the palaeochannel trophic characteristics, is the result of groundwater input, low sediment load overbank flows or peat mineralisation (Chapter 7, Section 7.2.3).

At the top of the core, zone 6 from 25cm depth to the surface shows a marked change in the vegetation development of the palaeochannel. The macrofossil record displays an increase in grassland and ruderal species, Poaceae, *Cerastium fontanum,* and *Sonchus asper,* for example, and the establishment of species found in damp grassland, *Ranunculus repens, Glyceria fluitans* and *Rumex acetosa* (Fig 5.25). There is also a reduction in seeds from arboreal species. Therefore, an upper limit in the successional trend is evident from the macrofossil data within zone 6. In natural systems alder carr communities are often succeeded by alder-ash associations (Lambert 1951, Rodwell 1991). However, within zone 6,

the persistent species (including *Cerastium fontanum, Ranunculus repens, Juncus* spp., and *Epilobium palustre*) can be found in meadow habitats, and are tolerant of periodic waterlogging and grazing or mowing (Grime *et al.* 1990). There is also a marked decline in wetland and fen carr species including *Alnus glutinosa*, *Mentha aquatica*, *Carex* spp., *Solanum dulcamara*, with a corresponding increase in grasses (Poaceae and *Glyceria fluitans*) in palaeochannel DC7. *M. aquatica* and *S. dulcamara* both require a degree of shading and are susceptible to grazing which the aforementioned persistent species can tolerate. The sedimentary conditions of the zone, facies C, indicate low rates of sedimentation and a dominance of *in situ* organic matter accumulation (LOI values, Fig 5.25), in similarity to the conditions in the palaeochannel today. Rodwell (1995) suggests that a reduction in alder carr results from two factors, increased waterlogging and flooding, or livestock grazing. The absence of aquatic species and reduction in wetland species with the increase of ruderals and grasses implies the latter reason for the change in vegetation community. The macrofossil record therefore indicates partial removal or a limit to the expansion of woodland, alongside an increase in grazing and/or mowing. The vegetation composition of the macrofossil record in zone 6 corresponds with the contemporary surface vegetation, a grassland area, occasionally waterlogged in the topographic depression formed by the palaeochannel (Plate 5.5). Moreover, livestock grazing is an observed activity on the present floodplain. Overall zone 6 displays an end to the successional sequence of the palaeochannel development with the presence of resistant wetland grasses and reeds, which can be attributed to agricultural activity.

Chapter 6

Results & Analysis: Kellwood and Breconhill Sites

The study site at Kellwood covers a 1.4km reach of the River Irthing floodplain, immediately downstream of the Kingwater tributary (Fig 3.2). The reach drains a catchment area of 220km^2 and has a gradient of 0.00185. The northern valley floor varies between 600 and 100m across. On the southern side of the valley floor opposite the Dovecote and Kellwood sites, the Breconhill study site extends for 2.5km (Fig 3.2) and is highly variable in width (Fig 6.1). Results of floodplain geomorphological mapping and surveying along both the Kellwood and Breconhill study sites are detailed in Section 6.1. Following geomorphological assessment of the valley floor, two palaeochannel reaches; KW1 and KW2, located at the Kellwood site (Fig 6.1, Plate 6.1 and 6.2) were selected for detailed investigations. Results of the sedimentological and plant macrofossil analyses undertaken on each palaeochannel are described in Sections 6.2 and 6.3.

6.1 Floodplain Geomorphology

Kellwood Geomorphology

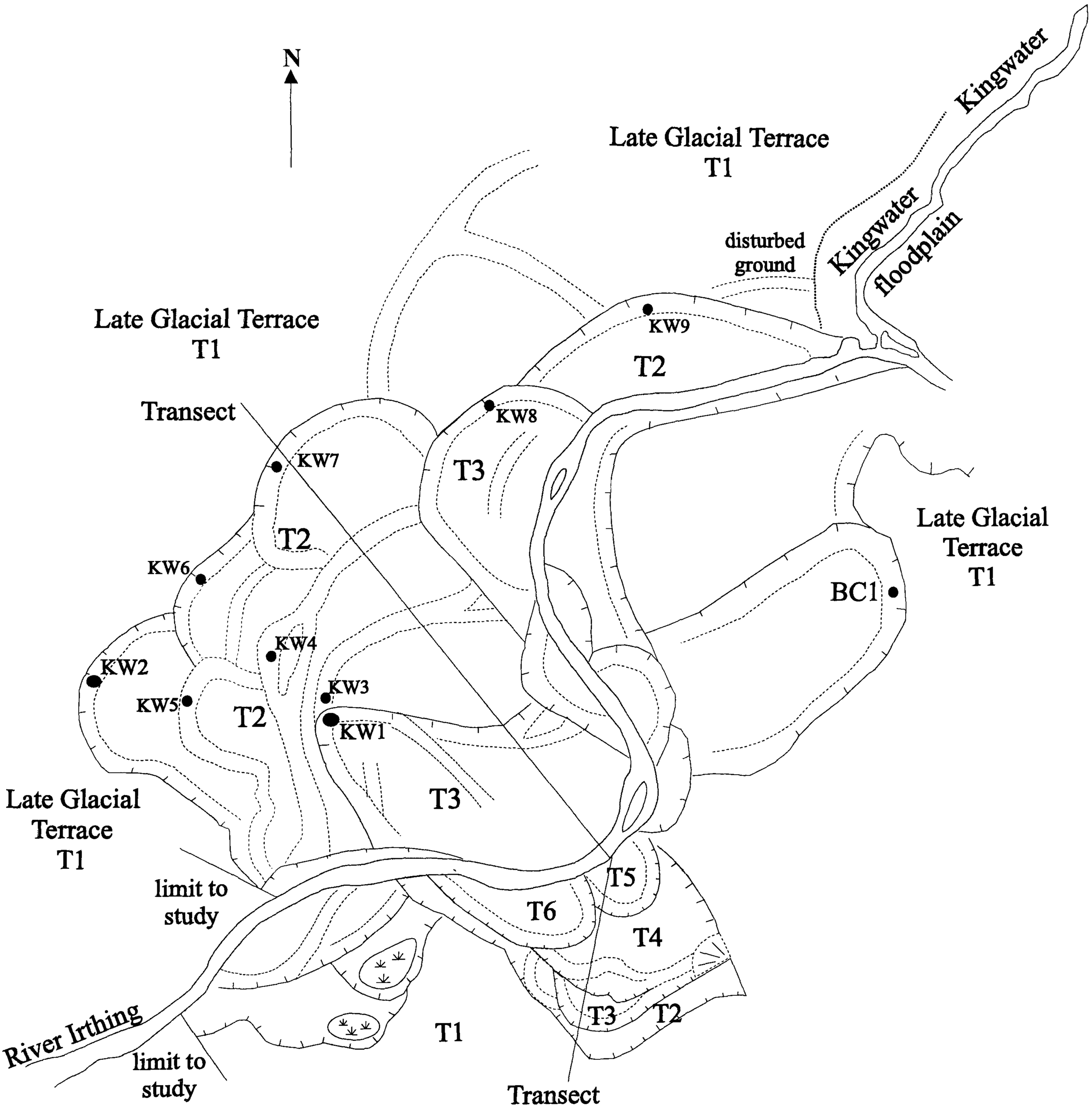
Geomorphological mapping and surveying of the Kellwood site revealed a valley floor of variable width with a well preserved series of fluvial terraces and associated palaeochannels (Fig 6.1). The cross section survey of Kellwood revealed a low floodplain relief (Fig 6.3) as the vertical valley floor morphology below high terrace T1 (Fig 6.1) was confined within 1.5m. This low relief limited the distinction of terrace units on the basis of height, therefore only three main terrace units are defined on the basis of chronology (Table 6.1). Details of the terrace units at Kellwood for which dating control has been obtained are provided below, followed by a description of each terrace and associated palaeochannels.

Kellwood Terrace Unit T1

The highest fluvial terrace on the valley floor at the Kellwood site, T1, follows a south-west north-east direction and at the downstream limit of the study reach the terrace is truncated by the contemporary channel (Fig 6.1). The terrace lies 5.5m above the active channel bed and is elevated over 3m above the lower terraces, from which it is separated by a steep terrace bluff (Fig 6.3). The surface morphology of the terrace reveals the preservation of a series of palaeochannel forms (Fig 6.1).

Figure 6.1

Kellwood and Breconhill Floodplain Geomorphological Map



Terrace T1 is interpreted as the late glacial-early Holocene fluvial terrace due to its height above the other fluvial terraces, similar to other high terrace units including T1 at the Dovecote site (Section 5.1) and common to upland catchment systems (Harvey 1985, Macklin 1999, Howard *et al.* 1999). The terrace unit has been laterally eroded and incised by the River Irthing to the south and the Kingwater to the east (Fig 6.1) since the end of the Devensian glaciation and therefore it is interpreted as delineating the limit of the Holocene valley floor.

Table 6.1 - Fluvial terrace heights and dates at the Kellwood site

Terrace	Height above channel bed	Dating Control
T1	5.5 m	**late glacial** (inferred)
T2	1.8-2.3 m	**380-40cal. BC (2160 ±60BP)** Bulk radiocarbon date (Beta-145547) from organic sediments in core KW2E (Fig 6.2) **670-970 cal. AD (1030 ±70 BP)** Bulk radiocarbon date (Beta-145548) from base of organic sediments in core KW2E (Fig 6.2) **880-1170 cal. AD (1220 ±60 BP)** Bulk radiocarbon date (Beta-147193) from above base of organic sediments in core KW2F (Fig 6.2)
T3	1.8 m	**1771-1882 AD** (historic maps-Fig 6.6)

Kellwood Terrace Unit T2

Terrace unit T2 incorporates seven distinct palaeochannel forms (KW2, KW3, KW4, KW5, KW6, KW7, KW9-Fig 6.1) . Table 6.2 describes these palaeochannel forms and associated sedimentary fills and terrace sections.

Table 6.2 Description of palaeochannel reaches associated with terrace unit T2 at Kellwood

Palaeo-channel	Description
KW2	KW2 is a sinuous palaeochannel reach located at the downstream part of the Kellwood site, 2.3m above the active channel bed (Fig 6.4). The palaeochannel is permanently waterlogged and dominated by reeds and wetland grasses (Plate 6.2) while a sparse presence of hardwood trees can be found on the terrace bluff. Detailed sediment coring of the palaeochannel fill and floodplain sediments noted a complex stratigraphy of coarse sands beneath the terrace surface and peaty silts and clays

within the palaeochannel fill (Fig 6.14). Sediment coring also revealed a complex former channel bed morphology (Fig 6.13) with only a thin veneer of gravel sediments lining parts of the palaeochannel beneath which was red sandstone bedrock (Section 6.3.2).

Two radiocarbon dates were initially obtained from palaeochannel fill organic sediments of KW2 between 76-85cm depth and 53-61cm depth (Fig 6.2) which produced dates of **670-970 cal.AD** (1030 ±70 BP) and **380-40cal.BC** (2160 ±60BP) respectively (Table 6.1). As the more shallow sediment produced an older date than the basal organic sediments, an anomaly existed between the dates. Consequently a third radiocarbon date was obtained from a proximal core at 78-88cm depth (Fig 6.2) which produced a date of **880-1170 cal.AD** (1220 ±60 BP). The correspondence between the basal organic dates, 670-970 cal.AD and 880-1170 cal.AD, suggests that the older date resulted from contamination, potentially during a period of floodplain disturbance (Section 6.3.3).

KW3 The terrace section associated with KW3 is located 1.9m above the active channel bed (Fig 6.4). The palaeochannel is truncated upstream by palaeochannel KW8 and downstream by KW1 (Fig 6.1). Coring of the palaeochannel has revealed 80cm of fine and medium sand overlying 40cm of peaty silts and organic fine sand which have accumulated over coarse gravel.

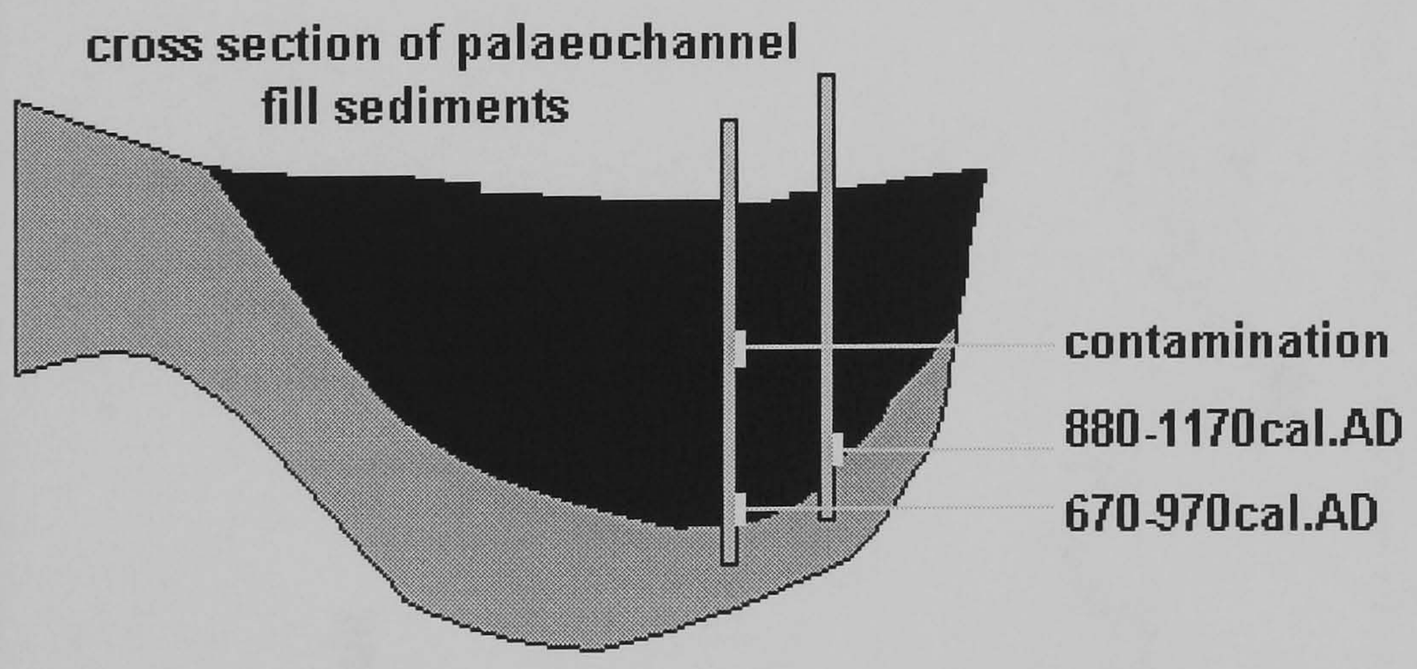
KW4 Palaeochannel KW4 has a low sinuosity and locally wider channel belt as the surface morphology features a mid channel bar form (Fig 6.1). The surface of the terrace section associated with the palaeochannel is 2.0m above the active channel bed (Fig 6.4). Coring of the palaeochannel infill sediments revealed 30cm of fine sand with organic inclusions above coarse gravels and beneath 100cm of medium-fine sands. The palaeochannel is truncated upstream by palaeochannel KW8 and downstream by the active River Irthing.

KW5 The terrace section associated with palaeochannel KW5 lies 1.8m above the active channel bed (Fig 6.4). The sinuous palaeochannel follows the line of a present day drainage ditch, cuts through palaeochannel KW6 and is truncated upstream by palaeochannel KW4 and downstream by the active channel (Fig 6.1). Coring of KW5 revealed 120cm of fill sediments above coarse gravels comprising 40cm of top soil above 80cm of peaty fine sands and silts.

KW6 Palaeochannel KW6 is located at the base of the high T1 fluvial terrace (Fig 6.1) with its terrace surface 1.4m above the active channel bed (Fig 6.4). Coring revealed

	230cm of infill sediments within KW6 comprising organic fine sands and silty peats. The palaeochannel cuts through palaeochannel KW2 and is truncated upstream by KW7 and downstream by KW5 (Fig 6.1).
KW7	Palaeochannel KW7 forms a meander loop along the base of the terrace bluff of high terrace T1 (Fig 6.1), cuts through palaeochannel KW6 and is truncated by palaeochannels KW4 and KW8. The terrace surface next to KW7 lies 1.8m above the active channel bed (Fig 6.4). The palaeochannel has infilled with 170cm of peaty fine sands and silts. One section of the palaeochannel is bordered by a fence, not subjected to livestock grazing and consequently, contains dense wetland and woodland vegetation dominated by the species *Phalaris arundinacea, Urtica dioica* and *Angelica sylvestris*.
KW9	The low sinuosity palaeochannel KW9 is located along the upstream section of Kellwood at the base of the terrace bluff of high terrace T1 (Fig 6.1). The associated terrace lies 1.9m above the active channel bed (Fig 6.4). Few organic remains were present in the infill sediments which comprised 135cm of fine and medium sands. The floodplain of the Kingwater tributary lies upstream of the palaeochannel while downstream is truncated by palaeochannel KW7.

Figure 6.2 Schematic representation of the location of bulk sediments for radiocarbon dates in KW2



In summary, the planform geomorphology of terrace T2 reveals a series of palaeochannel forms with a predominance of unconformable palaeochannel junctions and no surface morphological evidence (such as scroll bars) for the lateral reworking of the floodplain (Fig 6.1). Many of the palaeochannels contained organic fill sediments. The geomorphology suggests that the terrace has been formed by a series of avulsions whereby the channel has abruptly abandoned its course for a new one (Slingerford & Smith 1998). Although discrete terraces within T2 cannot be determined due to the low valley relief and limited dating

River Irthing Floodplain Cross-Section: Breconhill to Kellwood

Figure 6.3

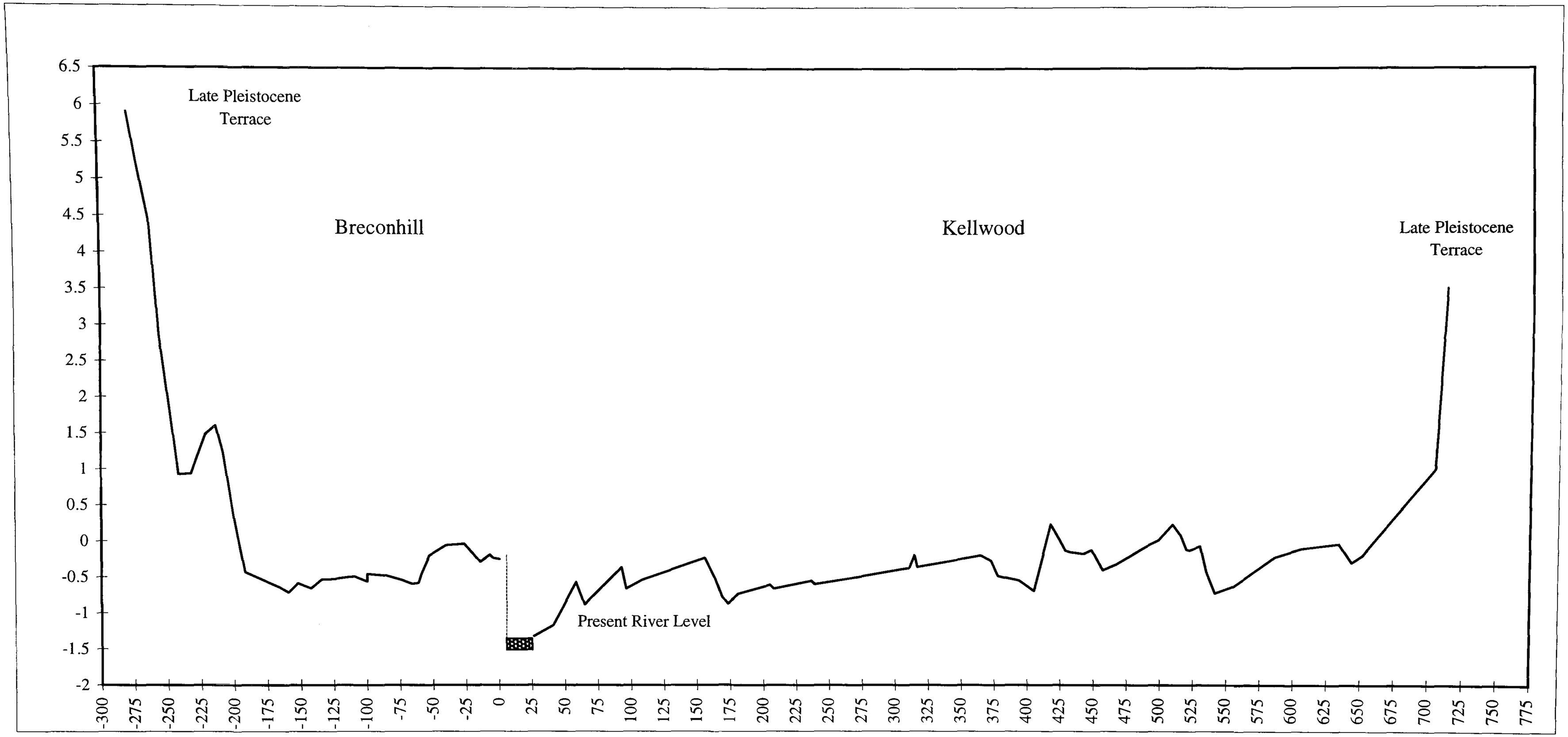
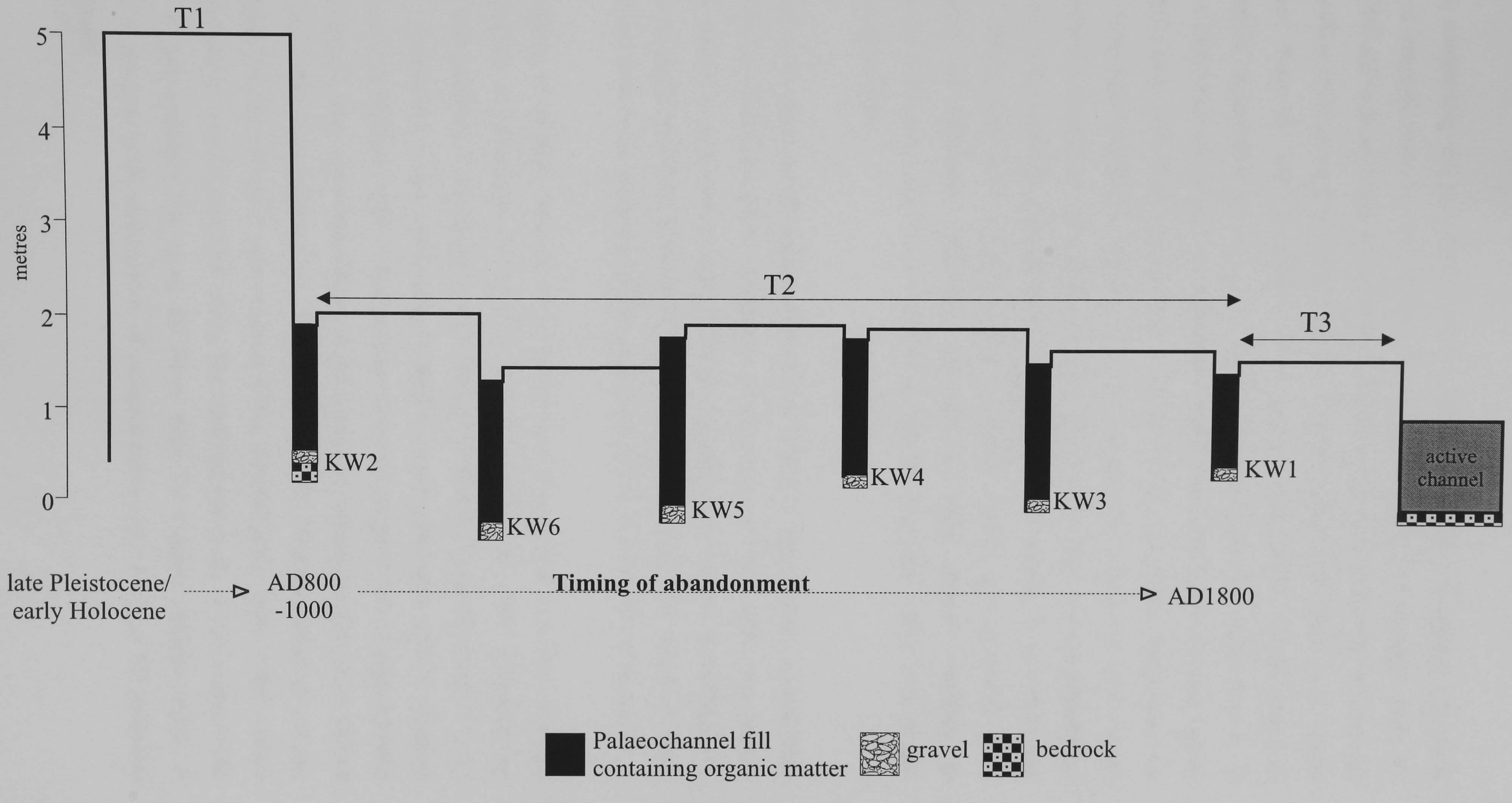


Figure 6.4

Schematic Kellwood Terrace Sequence



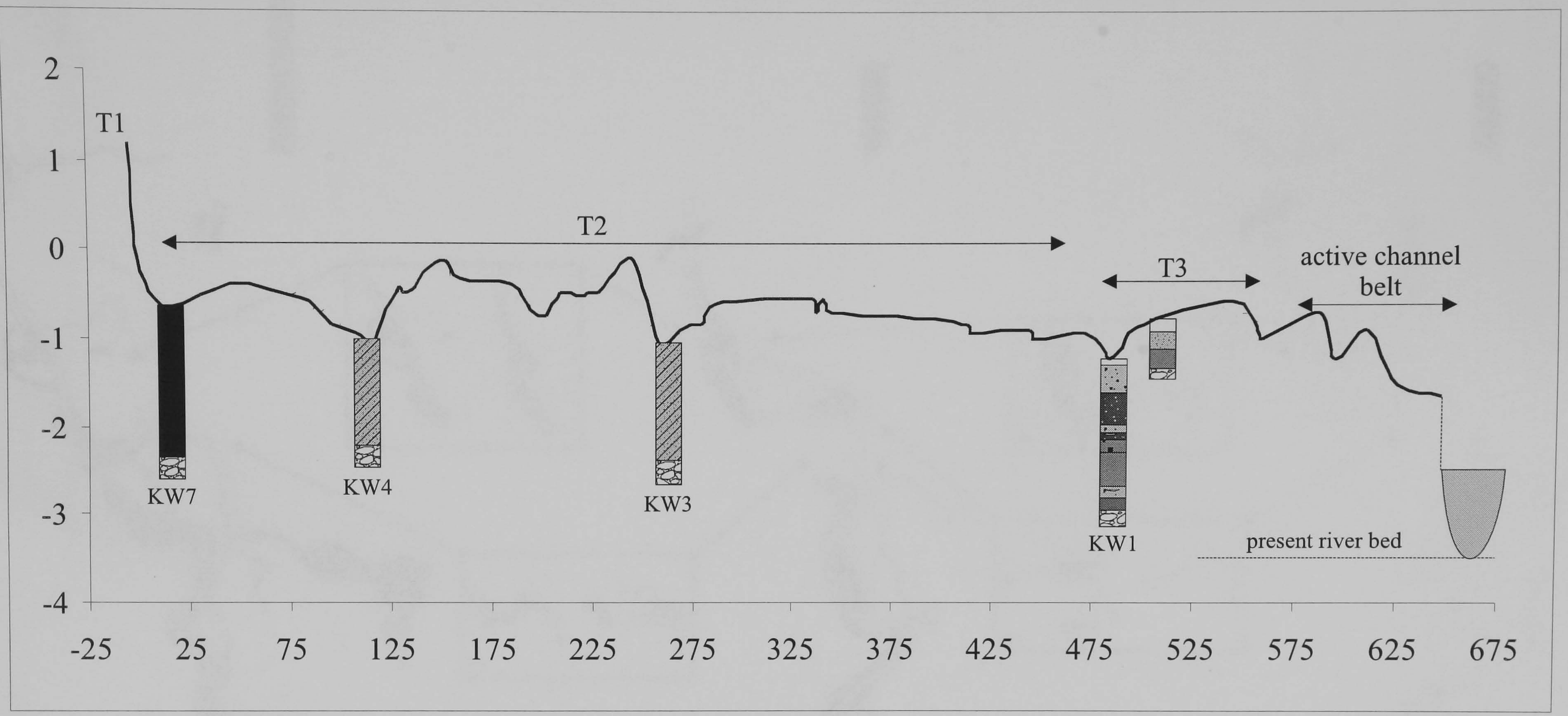
control, the morphology and unconformity of the palaeochannel reaches suggests a temporal sequence of channel avulsions. Palaeochannels KW5 and KW7, for example, both cut through KW6 and both are truncated by KW4 (Fig 6.1) indicating a chronology of avulsion. The radiocarbon dates taken from basal sediments of palaeochannel KW2 (Table 6.1), which lies furthest from the active channel and is possibly the oldest of the Holocene palaeochannels, suggest that the age of the present preserved Holocene valley floor is, at most, *circa* 1300 years old. From work undertaken in the Vistula catchment, Poland, Kalicki *et al.* (1991) have seen how, during high discharge events, floodplain depressions are inundated eventually leading to avulsion. The new channel thus follows the route of the former floodplain depressions. As palaeochannels forms valley floor surface depressions (Lewin 1992), if the avulsions at Kellwood occurred as asserted by Kalicki *et al.* (1991), then the River Irthing may have re-entered former channel courses and re-worked older palaeochannel fill sediments. Therefore, although the basal organic sediments in palaeochannel KW2 may only date to 670-970cal.AD, the remaining valley floor terrace sediments may be older.

As depicted by the Holocene floodplain cross section (Fig 6.3), there is little vertical relief across the Kellwood terraces which, combined with the young age of the valley floor implies that no net vertical incision into the valley floor has occurred since, at least, 670-970cal.AD. However, the height difference between T1 and the Holocene valley floor (Fig 6.4) shows over 3m of fluvial incision into glacio-fluvial gravels prior to the construction of terrace T2.

The implication of frequent avulsions on palaeochannel development is evident from the sedimentological characteristics of the fills. Organic remains and peaty sediments are preserved in the majority of the palaeochannels along both terraces T2 and T3 (Table 6.2 and Fig 6.4), a comparatively rare phenomena in British upland catchment systems (Tipping 1995, Passmore & Macklin 1997). Their presence indicates the slow rate of palaeochannel infilling, persistent high water table (linked to the absence of vertical incision) and a limited reworking of valley floor sediment (cf. Moores *et al.* 1999). However, although organic palaeochannel fills are prevalent, palaeochannel KW2, potentially the oldest within terrace unit T2, has infilled over the past 1300 years. The relatively young age of this sediment fill, compared to palaeochannel fills along the River Rede for example (Moores 1998), is interpreted as relating to the reoccupation of palaeochannels and erosion of fill sediments during avulsion.

Figure 6.5

Kellwood Floodplain Cross Section of Terraces and Palaeochannels



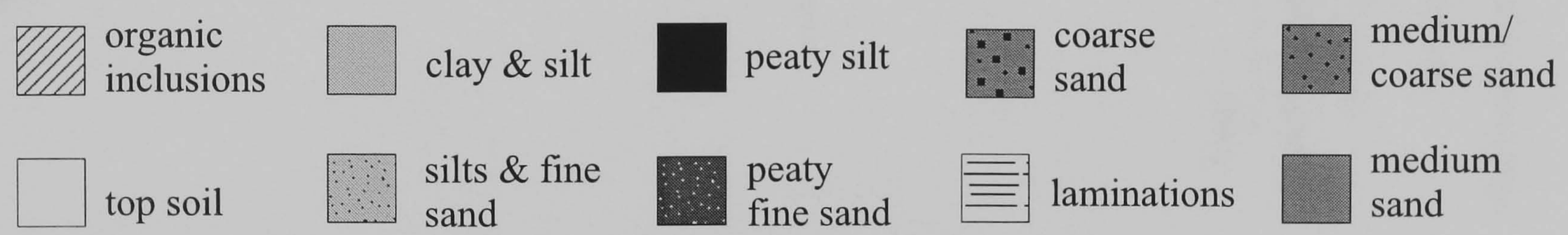
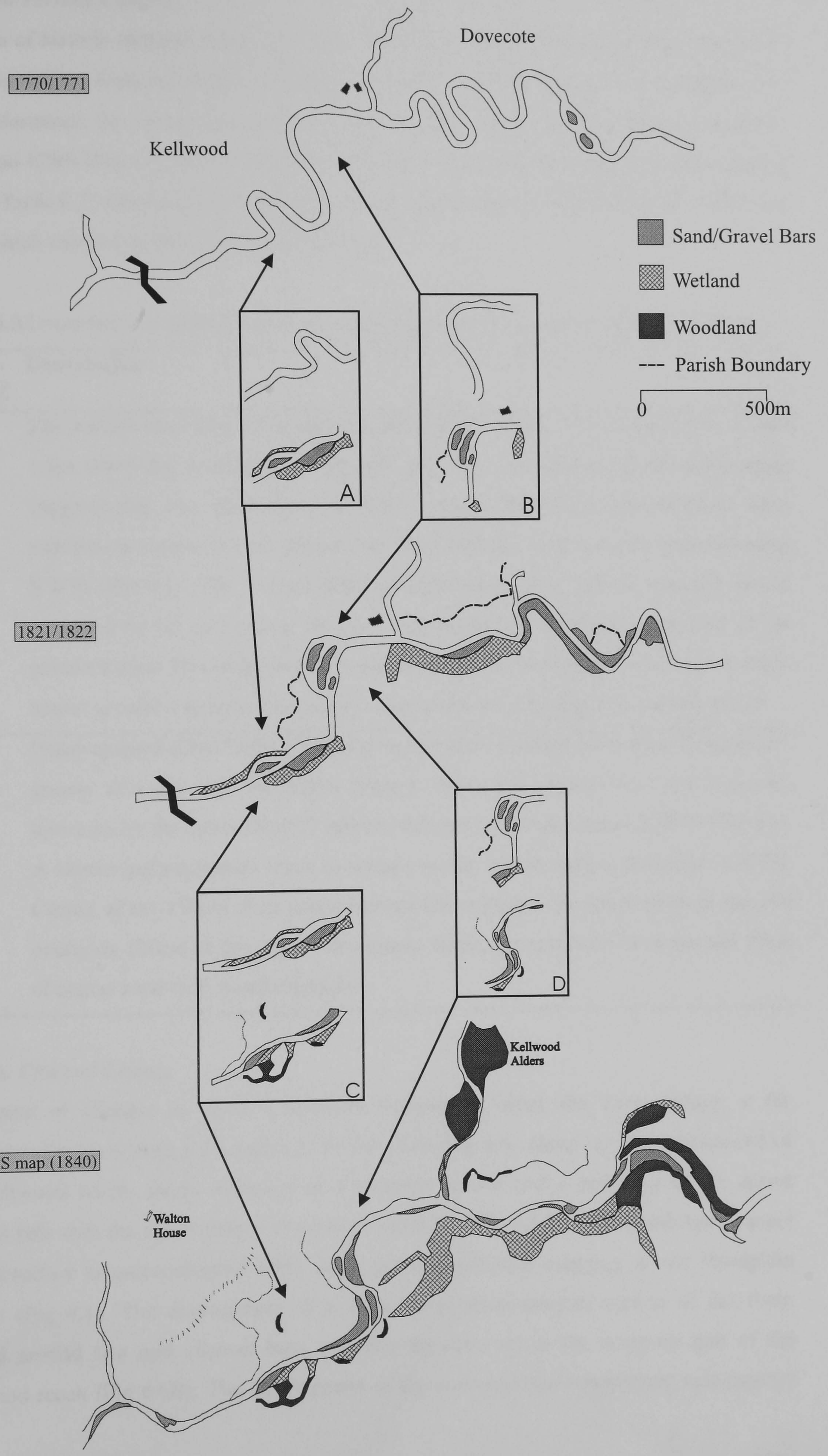


Figure 6.6

Kellwood Site Channel Change 1771-1822 & 1822-1840



Kellwood Terrace Unit T3

Analysis of historic channel change along the Kellwood reach, based on the former routes of the River Irthing from old maps surveyed in 1771-72, 1821-22, and the 1840s (Table 4.1) have determined the chronology of terrace unit T3 and associated palaeochannel reaches, KW1 and KW9 (Fig 6.1). The characteristics of the terrace and palaeochannels are detailed below (Table 6.3) followed by a description of historical channel change along the Kellwood reach which resulted in the formation of terrace T3.

Table 6.3 Description of palaeochannel reaches associated with terrace unit T3 at Kellwood

Palaeo-channel	Description
KW1	The terrace associated with palaeochannel KW1 (Fig 6.1) is located next to and 1.8m above the contemporary channel (Fig 6.4). The palaeochannel morphology suggests that two generations of KW1 existed. The older palaeochannel form exhibits an upstream mid channel bar form which is truncated by palaeochannel KW10 (Fig 6.1). The younger KW1 palaeochannel has a greater sinuosity and is truncated by the active river channel. High resolution sedimentary analysis of the palaeochannel fill sediments has revealed a complex stratigraphy of coarse-medium lateral accretion deposits and organic fine sands and silts (Fig 6.9, Section 6.2.2).
KW9	Palaeochannel KW9 forms a meander bend which is inset with terrace T2 and has a greater sinuosity than the active channel. The palaeochannel has been truncated upstream by the active channel and downstream by palaeochannel KW10 (Fig 6.1). A shorter palaeochannel reach is evident on the terrace surface proximal to KW9. Coring of the 170cm deep palaeochannel fill sediments revealed 30cm of top soil overlying 130cm of fine sand with organic inclusions and peaty horizons and 10cm of coarse sand with wood fragments.

Historic Channel Change

Evaluation of changes in channel planform morphology along the River Irthing at the Kellwood site, from maps surveyed in 1771 and 1821 (Fig 6.6), along the downstream end of the Kellwood reach, shows evidence of a meander cut-off and a widening of the active channel belt with the development of a mid channel bar (Fig 6.6A). The abandoned channel was identified as palaeochannel KW1 from geomorphological mapping of the floodplain surface (Fig 6.1). The development of a wide active multi-channel section of the river, divided around two mid channel bars, can also be observed in the upstream part of the Kellwood reach (Fig 6.6B). The development of the upstream and downstream mid-channel

bars and the widening of the channel suggests localised increase in sediment load or the downstream movement of coarse sediment (Passmore *et al.* 1993). A degree of lateral reworking of floodplain sediments, as indicated by channel widening, has also occurred.

River planform change between 1821 and the 1840's, the survey date for the 1st edition Ordnance Survey map, near to the location of the meander cut-off (Fig 6.6A) includes the development of an area of wetland on the south side of the former mid channel bar (Fig 6.6C). The younger map also details channel change along the Kellwood reach, consisting of a rationalisation of the active channel around the meander bend as the series of mid channel bars is no longer present, having been replaced by a smaller mid channel bar and point bar (Fig 6.6D). This channel rationalisation resulted in the formation of palaeochannel KW9 (Fig 6.1). In addition, the development of a mid channel and point bar downstream of the meander are evident on the 1840 map (Fig 6.6D).

The development of the wetland area at the location of the downstream mid-channel bar signifies the preferential re-routing of the channel around the north side of the bar, instigating the infilling of the southern arm, while the removal of the mid channel bars from the upstream section of the reach implies localised sediment transfer. A downstream transfer of sediment with the development of both mid-channel and point bars, downstream of the original multi-channel section of the river is also indicated by the historical channel planform changes (Fig 6.6D).

Breconhill Geomorphology

The Breconhill study site lies on the southern bank of the River Irthing valley floor. The valley floor width is variable but generally more narrow than the floodplain at Dovecote and Kellwood (Fig 5.1 and 6.1). Upstream of the Kingwater tributary opposite the Dovecote site, the valley floor is confined due to the presence of glacial till deposits (Plate 3.2), and thus mainly comprises the active channel belt. Downstream of Kingwater, opposite the Kellwood site, the floodplain at Breconhill widens at three locations. These three wider floodplain reaches are described below.

The furthermost upstream widened valley floor reach, on the southern side of the River Irthing floodplain opposite the Kellwood site is set against a steep terrace bluff. Geomorphological mapping indicated the presence of a sinuous palaeochannel set against the edge of the valley floor (BC1, Fig 6.1). The palaeochannel contained an oxbow lake of up to 1m depth and surrounded by dense vegetation. A sediment core extracted from the

palaeochannel revealed 1.5m of fine sands and silts with organic inclusions. Three smaller terrace sections with associated palaeochannels, closer to the active channel belt were also present.

Located opposite terrace unit T3 and palaeochannel KW1 at Kellwood, the River Irthing floodplain widens. Geomorphological mapping and surveying has revealed six fluvial terrace units, distinguished on the basis of terrace heights (Table 6.4), a series of sinuous palaeochannel forms and a former alluvial fan (Fig 6.1). Surveying of the valley floor revealed a low relief below terrace unit T3 (Fig 6.7, Table 6.4) which lay 2.75m above the active channel bed.

Figure 6.7 Valley floor cross section at Breconhill (transect location on Fig 6.1)

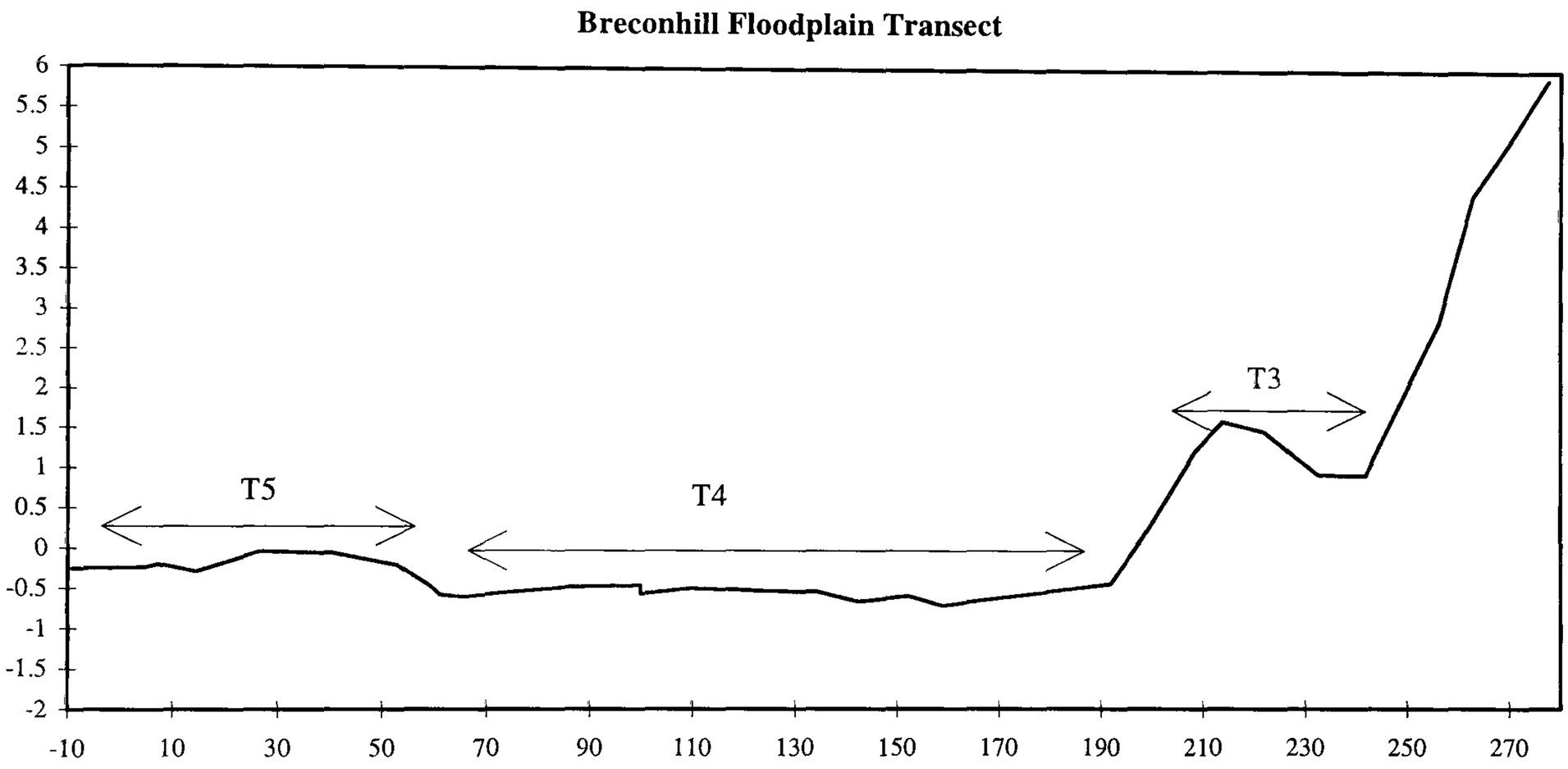


Table 6.4 Breconhill Fluvial Terrace Units

Terrace Unit	Height above present river bed	Terrace Unit	Height above present river bed
T1	7.8m	**T4**	2.3m
T2	4.9m	**T5**	2.8m
T3	4.4m	**T6**	2.0m

At the furthermost downstream section of the Breconhill site, floodplain mapping revealed two waterlogged flood basins and a lower terrace with low sinuosity palaeochannel forms (Fig 6.1). This section of the floodplain was confined by glacial tills (Fig 3.4) and was densely vegetated due to the absence of livestock grazing. Coring of one of the flood basins (BC2) revealed 2.5m of peaty silts and fine sands with occasional coarse sand lenses.

The preliminary surveying and mapping of the Breconhill floodplain displays a distinct valley floor morphology, sections of which contrast with the northern valley floor. Surveying data of terrace units across the whole valley floor and between the upstream-downstream sections of the southern floodplain would enable correlation of the terrace units across the Breconhill site and across the southern and northern sections of the valley floor (between Kellwood and Breconhill-Fig 6.3). However, the variability in floodplain morphology between and within the two sites suggests that each has experienced a discrete form of Holocene floodplain evolution.

6.2 Results and Analysis for Palaeochannel KW1

A 100m section of palaeochannel KW1, located at the apex of the meander bend at the junction with palaeochannel KW3 (Fig 6.1), was the subject of high resolution sediment coring and plant macrofossil analysis. From historical maps it is known that the meander was abandoned between 1771 and 1822 (Fig 6.6A).

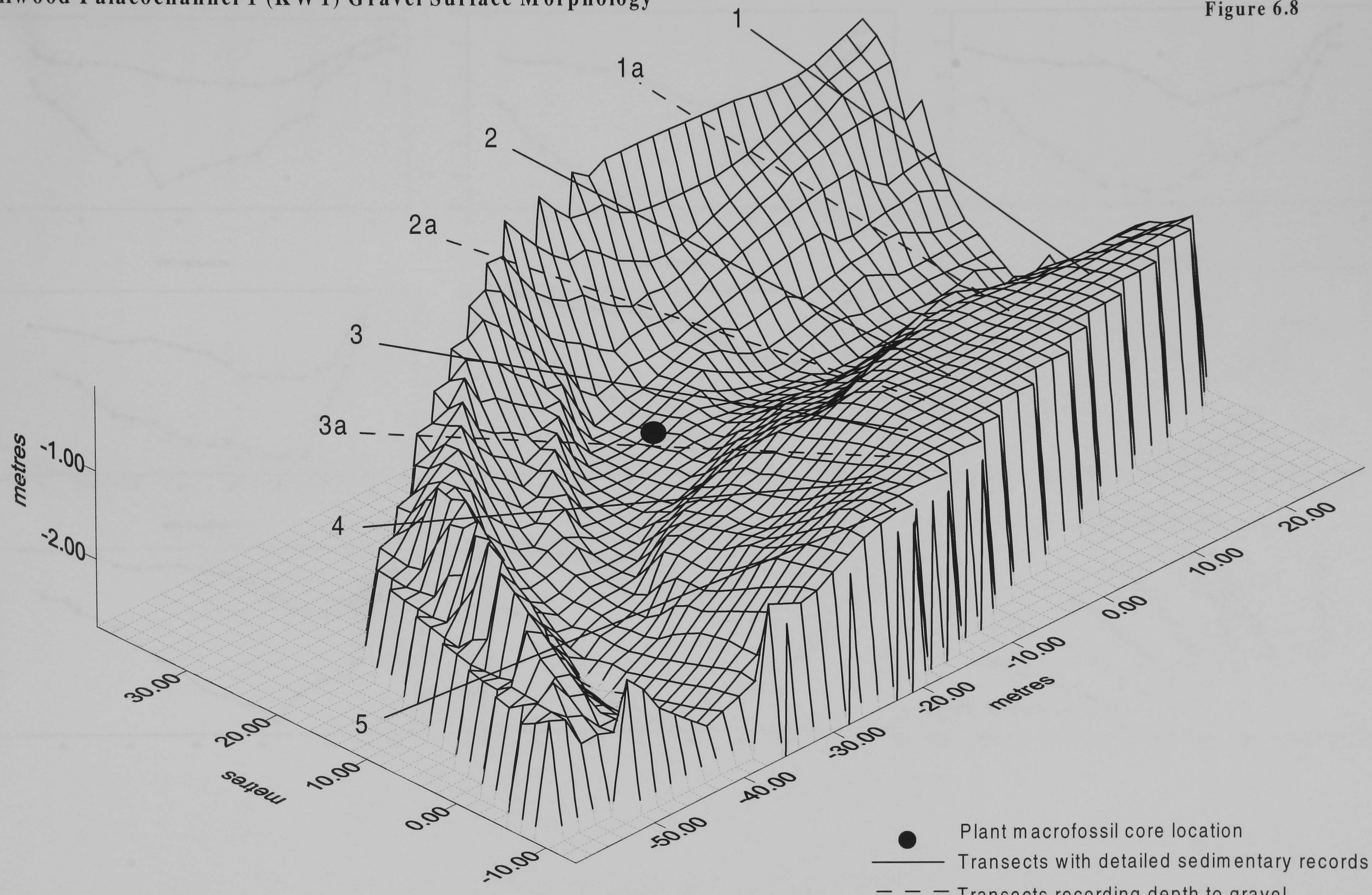
6.2.1 Palaeochannel geometry

Eight transects along the 100m palaeochannel section of KW1 were cored at 2m intervals (Plate 6.1) and at higher resolutions to record change of slope where required, to ascertain the dimensions of the gravel surface morphology (Fig 6.8) beneath the palaeochannel fill sediments. Each core location was surveyed (Fig 6.9). The distance between transect 1 and 5 was determined by estimating the former channel width from the surface morphology, in order to incorporate a riffle-pool-riffle sequence based upon a 1:7 width:riffle/pool spacing. Equal spacing between all transects was not always possible due to the presence of features such as alder trees on the upper terrace bluff.

The three dimensional reconstruction of the gravel surface morphology beneath the channel fill sediments of KW1 reveals a former meander bend (Fig 6.8) with, mostly, well defined channel sides (Fig 6.9). Transects 1 to 2 exhibit a greater symmetry in comparison to those downstream with transects 3 to 4 showing lower slopes on the left channel side than the right. Transects 1, 3 and 5 have variable gravel surface elevations close to the channel sides.

Kellwood Palaeochannel 1 (KW1) Gravel Surface Morphology

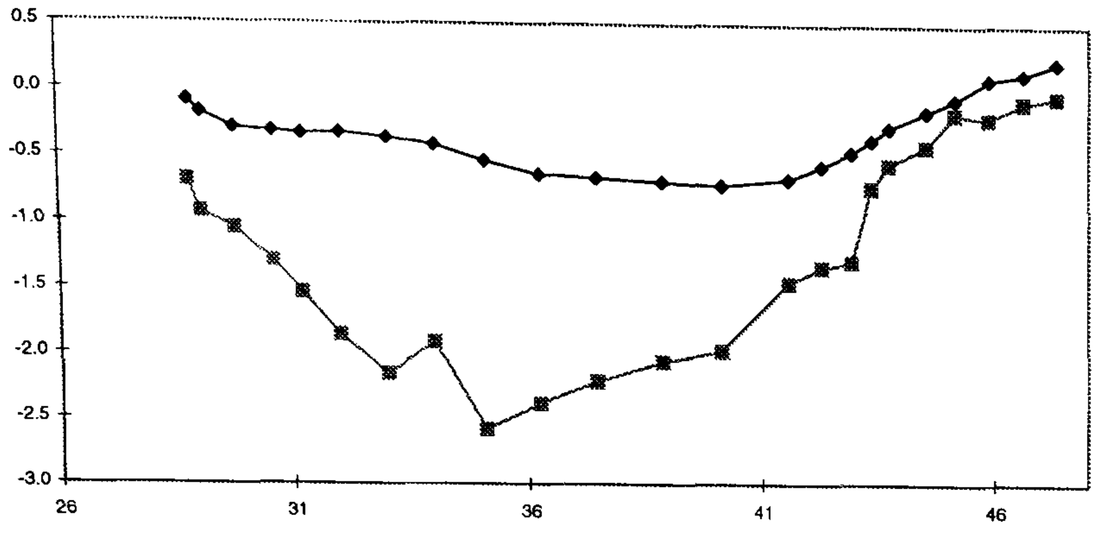
Figure 6.8



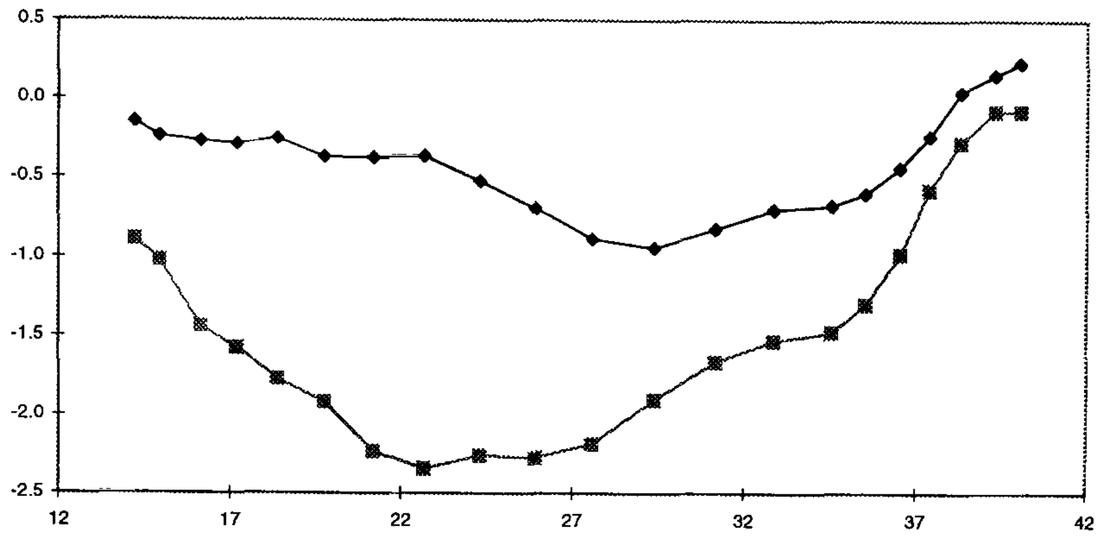
Kellwood Palaeochannel 1 (KW1) Gravel Surface Cross Section Profiles

Figure 6.9

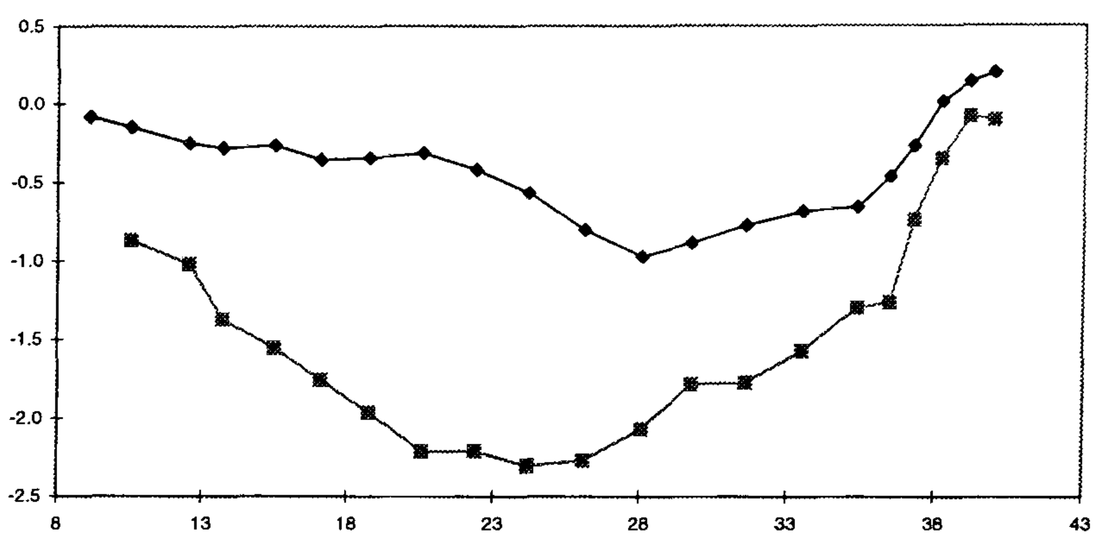
KW1 transect 1



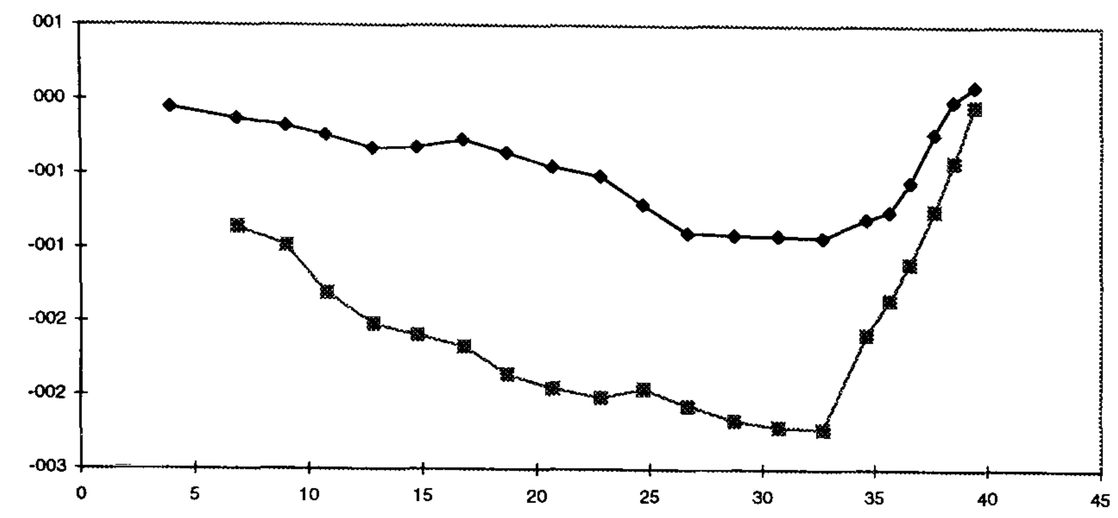
KW1 transect 1a



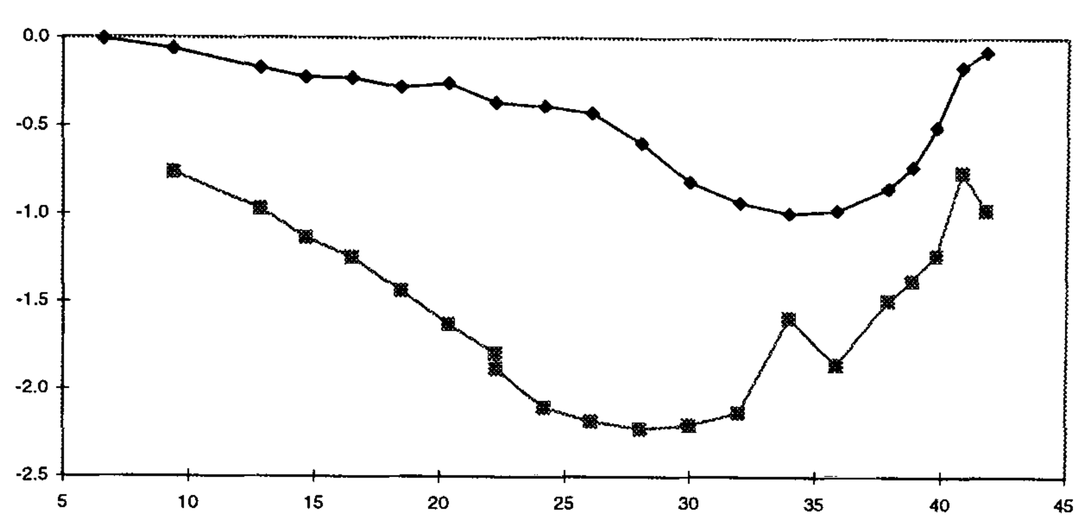
KW1 transect 2



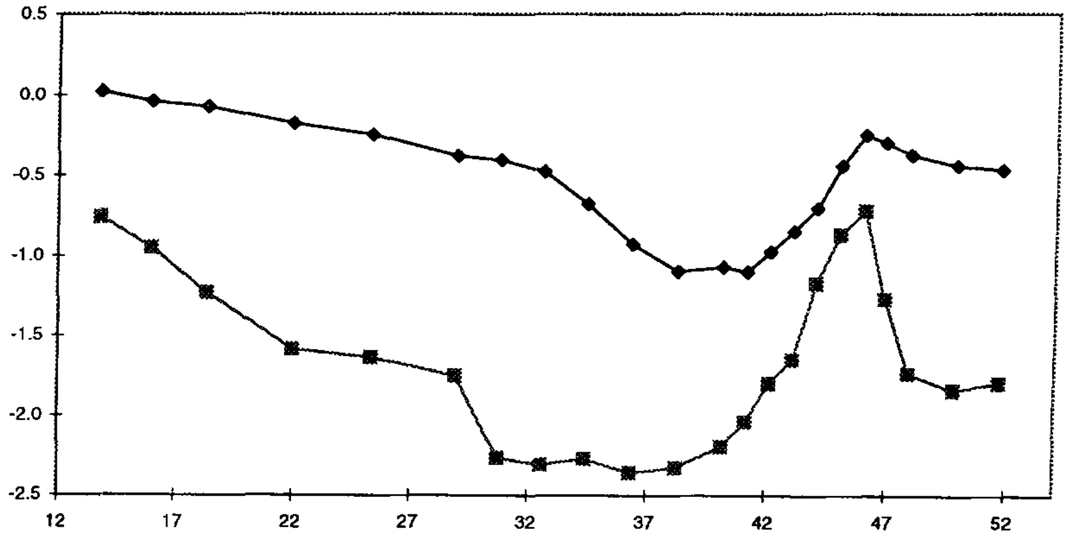
KW1 transect 2a



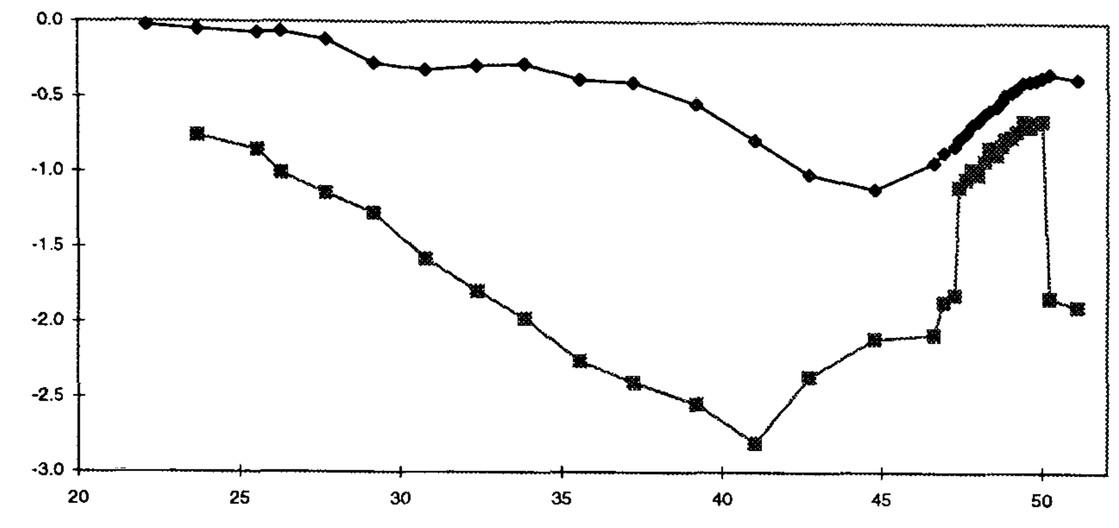
KW1 transect 3



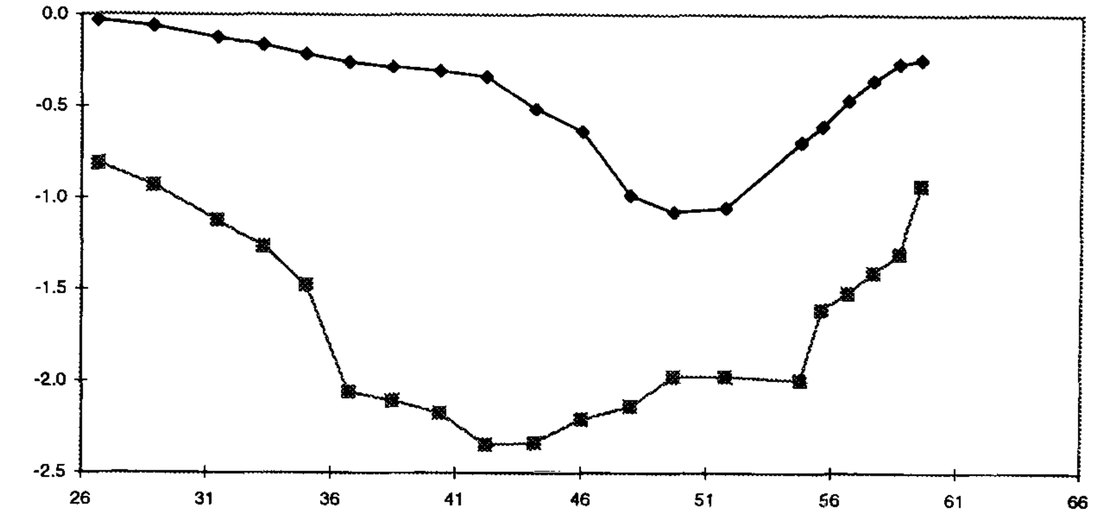
KW1 transect 3a



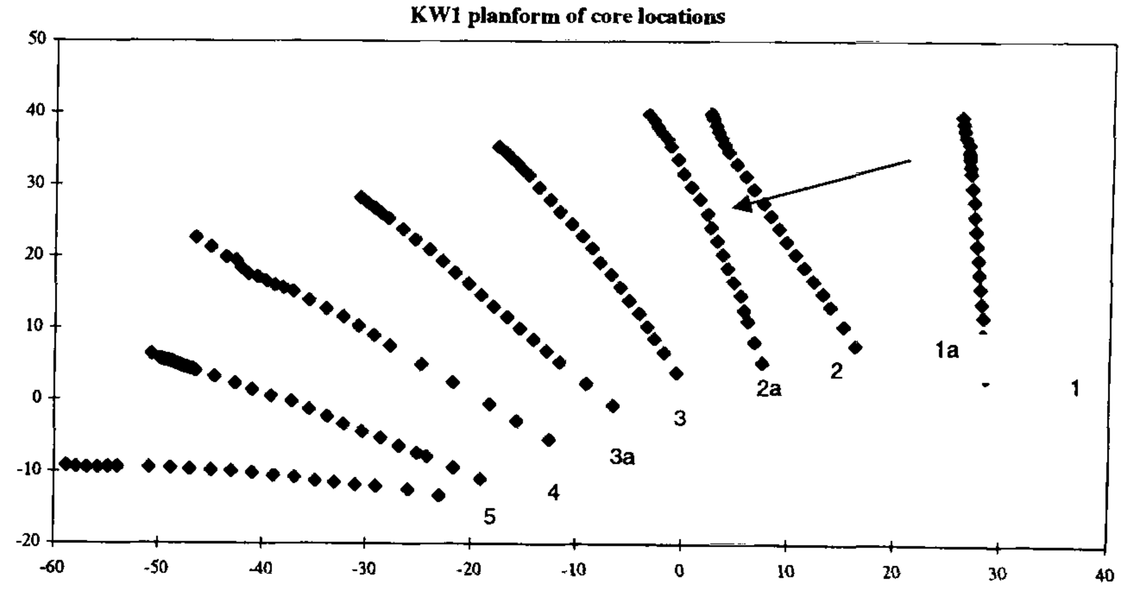
KW1 transect 4



KW1 transect 5



KW1 planform of core locations



From cartographic evidence, palaeochannel KW1 is known to be a section of a former, highly sinuous channel, abandoned in the late 18th century (Section 6.1, Fig 6.6). The upstream transects exhibit a relatively symmetrical gravel bed morphology, which shallows to become more asymmetrical downstream, representative of a pool at the upstream section of the reach followed by a former riffle. The asymmetry of transects 3a and 4, and the three dimensional reconstruction of the former channel bed show the channel to deepen and become confined to the outer meander bend. The deepening reflects erosion at the meander apex linked to the high sinuosity of the former channel.

Within transect 4, and to a lesser extent in transects 3a and 5, a hard solid feature exhibiting steep vertical edges, on the right bank of the channel, can be seen (Fig 6.9). Along transect 4 the feature was cored at 20cm intervals to ascertain a high resolution morphology. The right bank of transect 4 is located at the mouth of palaeochannel KW3, cut off by palaeochannel KW1, as seen from the geomorphological map and channel fill sediments (Fig 6.1 and Fig 6.10). Considering the historical age of the palaeochannel, the solid form of the feature and that, as a result of high sinuosity, the river will have been prone to lateral erosion, the feature in the downstream transects may be a former revetment. Furthermore, the organic, fine sandy sediments at the mouth of palaeochannel KW3 (transect 4-Fig 6.10) will have been easily eroded thus necessitating the construction of channel reinforcements.

6.2.2 Lithostratigraphy of channel fills in palaeochannel KW1

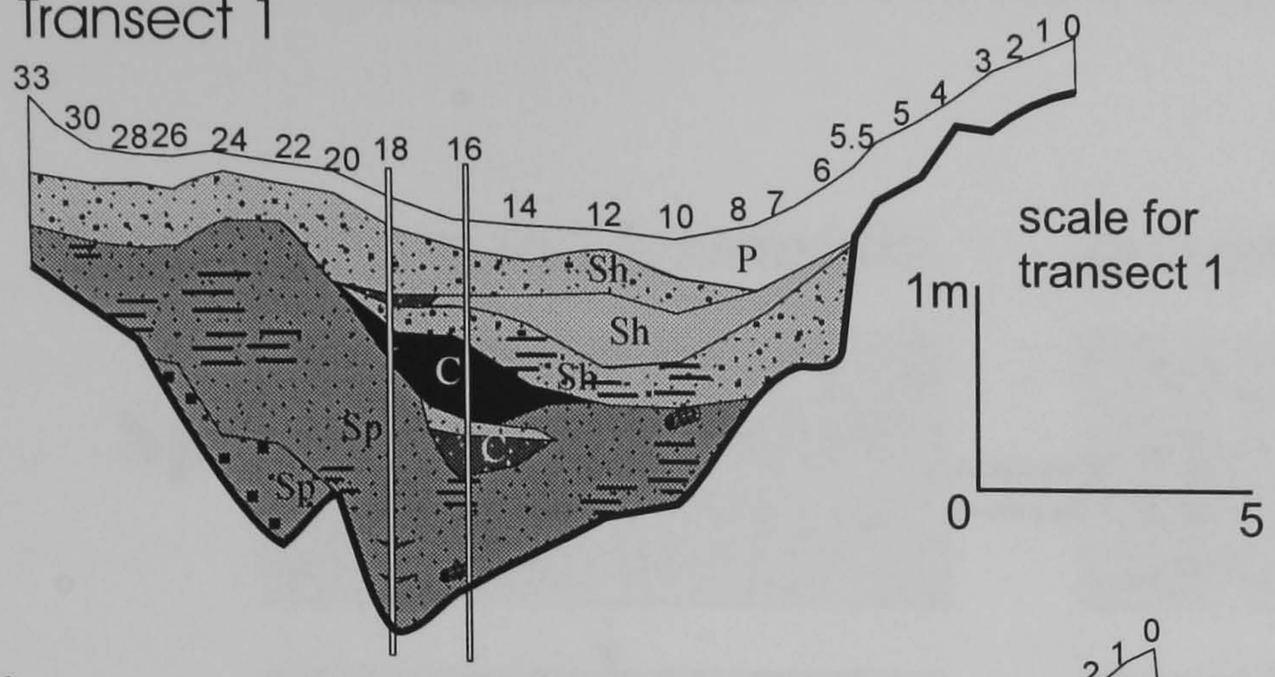
The results of the sediment logging (Plate 6.1) for KW1, along five of the eight transects cored across the palaeochannel (Fig 6.9) from transect 1 (the upstream transect) to transect 5 (the furthest downstream), are described and discussed below. Using the lithofacies classification (Table 4.2) the sediments within KW1 have been divided into facies representing specific depositional environments. A temporal sequence of palaeochannel infilling is shown in Fig 6.11.

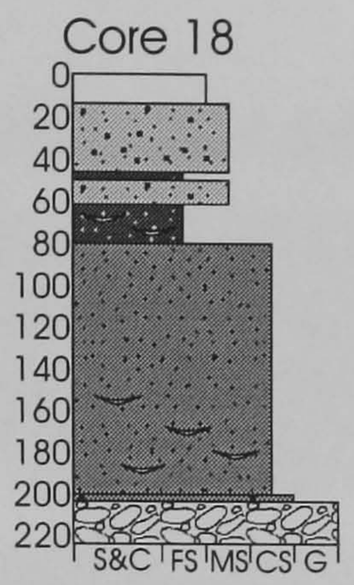
Overlying the gravel surface in all of the palaeochannel transects, on the inner meander bend, are coarse and medium/coarse sands with occasional fine/medium sand horizons and silty lenses (e.g. Core 18 Transect 1, Core 19 Transect 2, Core 17 Transect 4-Fig 6.10). Woody inclusions are evident at the base of the sediments in transects 1, 2 and 5 (e.g. Core 16 Transect 5-Fig 6.10). The sedimentation pattern reveals a persistent channel form suggesting that the material was deposited when flow was maintained through the channel potentially

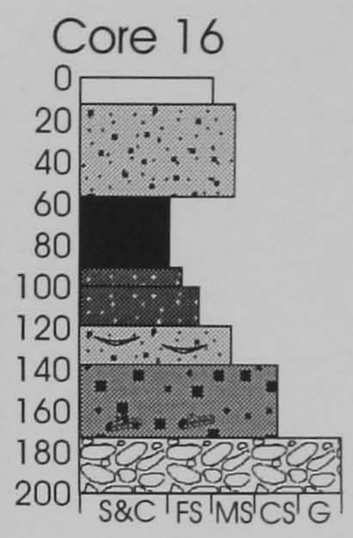
Kellwood Palaeochannel 1 (KW1) Sedimentary Infills

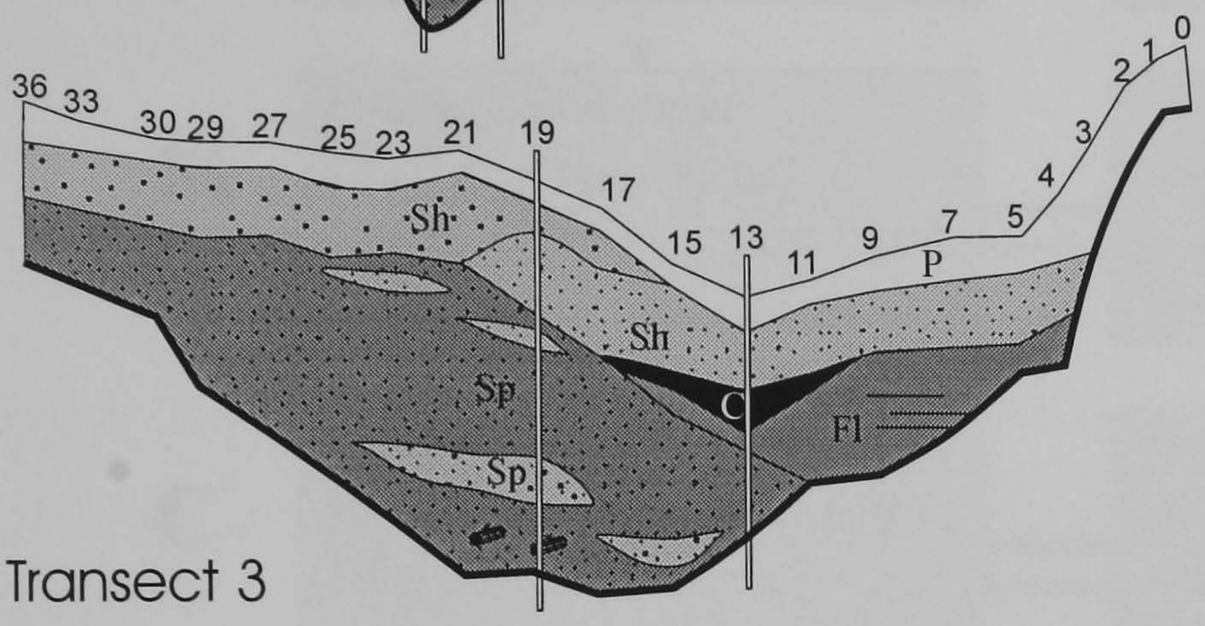
Figure 6.10

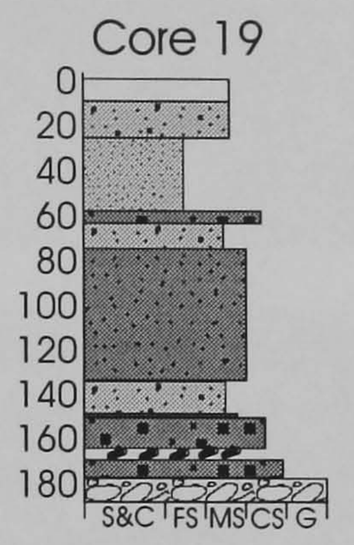
Transect 1

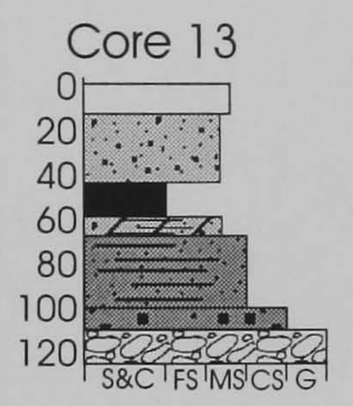




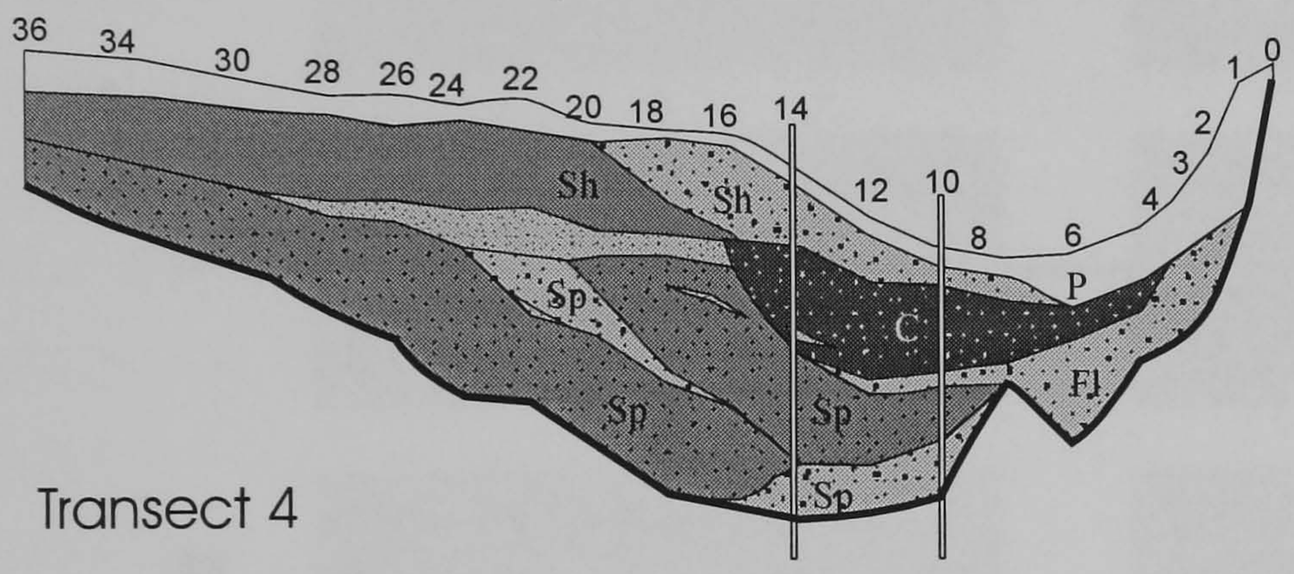


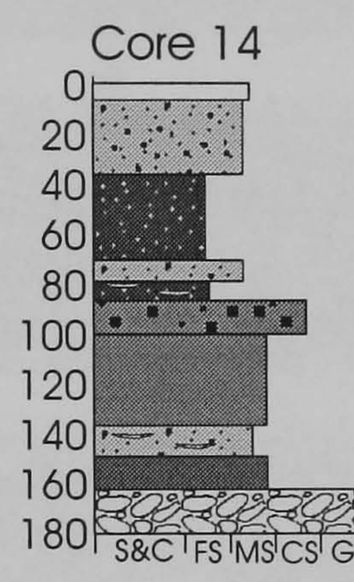


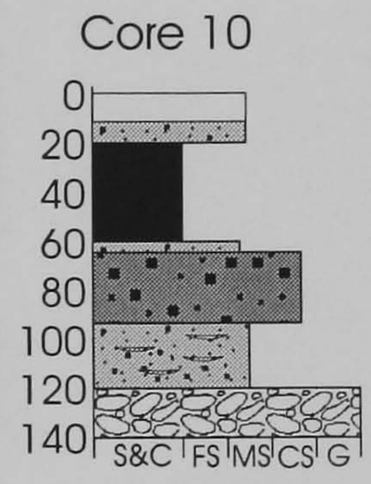




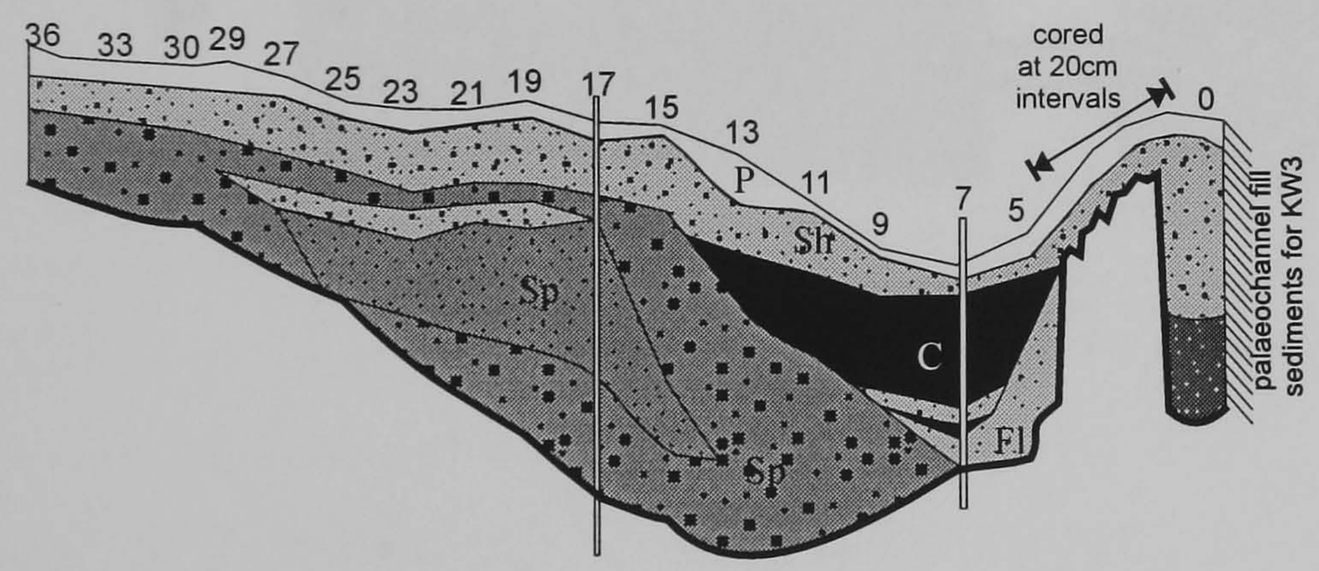
Transect 3

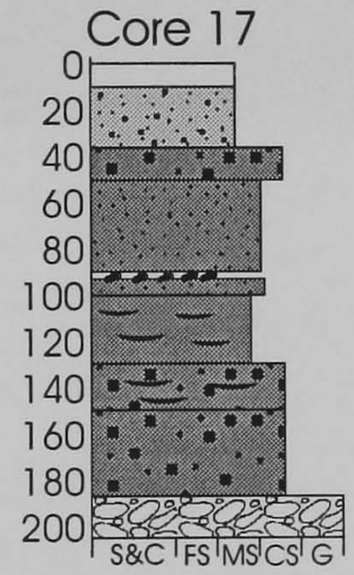


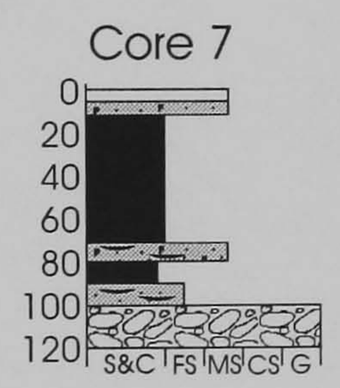




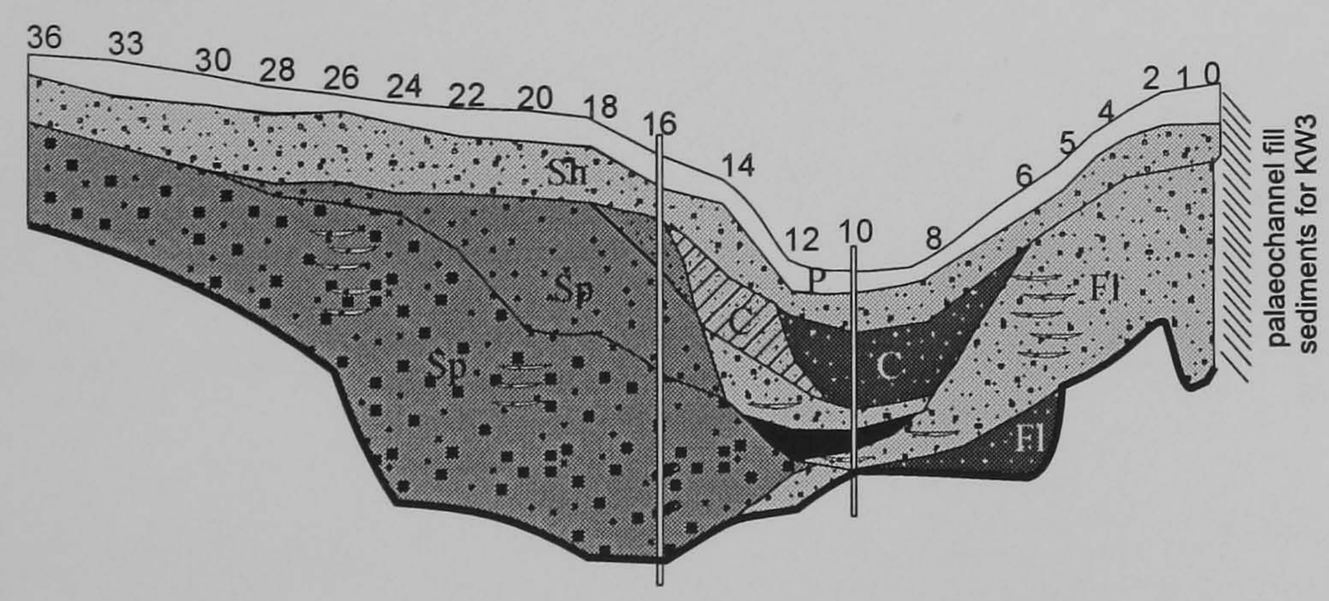
Transect 4

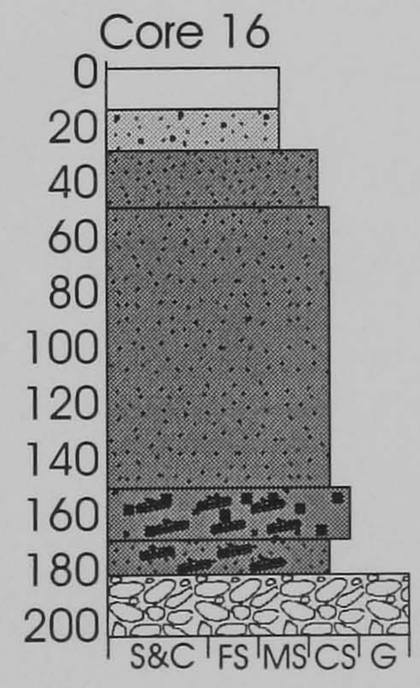


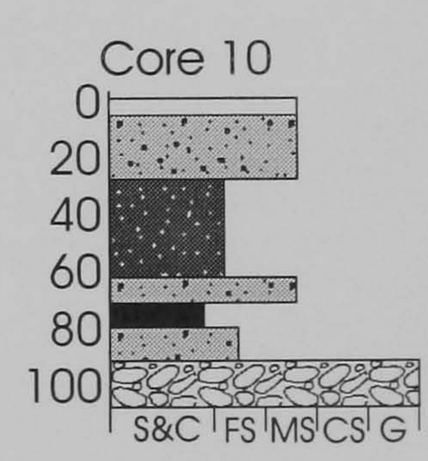




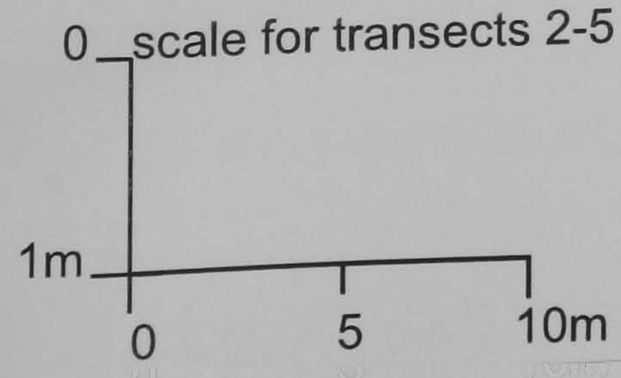
Transect 5







Left Channel Side

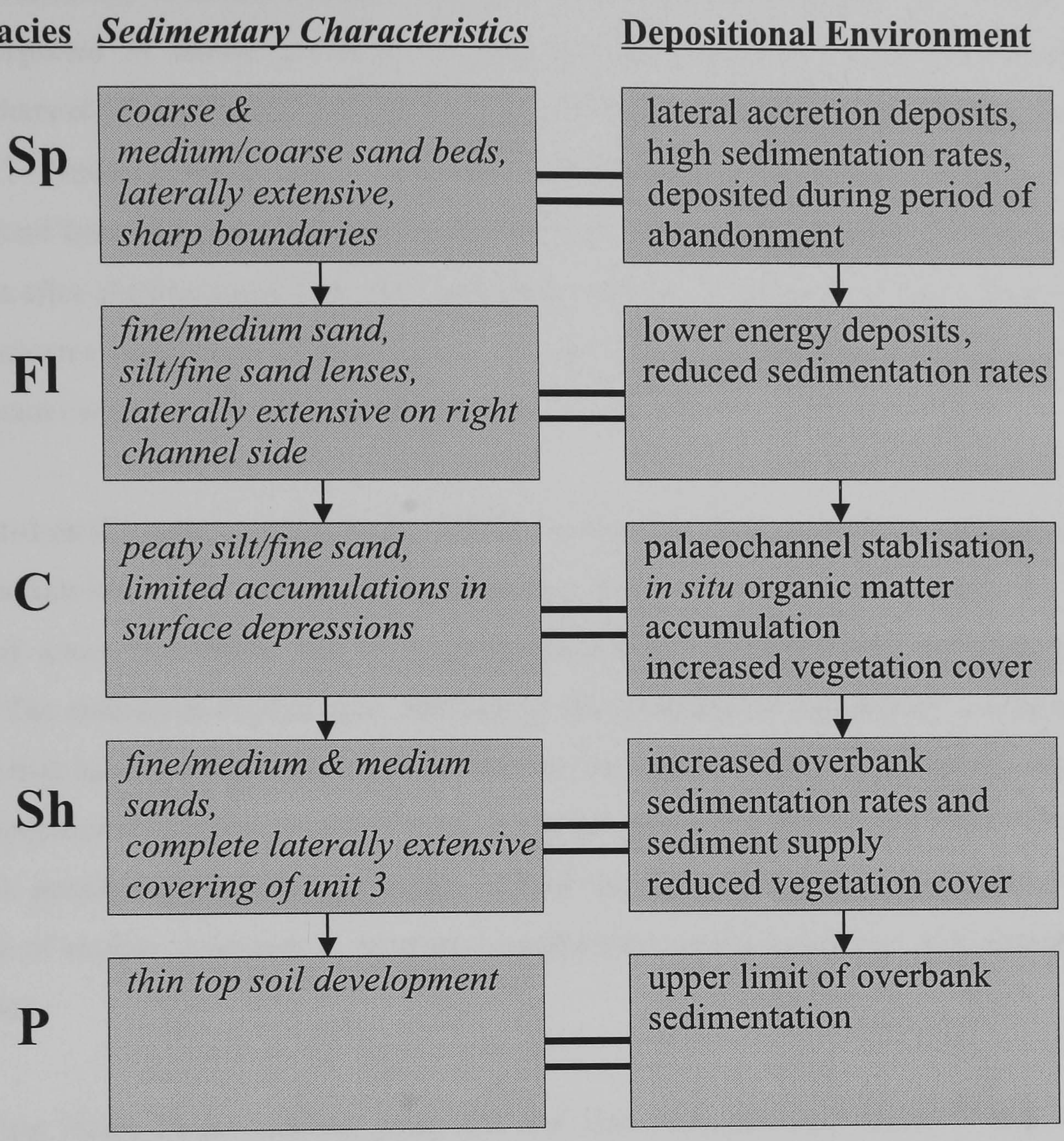


Right Channel Side

top soil
peaty silt
peaty fine sand
clayey silt
silts & fine sand
fine/medium sand
medium sand
medium/course sand
coarse sand
laminations
woody inclusions
gravel
gravel surface
organic inclusions
lenses
Sp facies
210 core locations

KW1 - Model of Sedimentary Deposition

Figure 6.11



during the period of channel abandonment. The fine lenses and laminations in the sand beds signify variability in sediment inputs and flow velocities. The sediments form facies Sp and are interpreted as lateral accretion or point bar deposits. The Sp facies dominate the palaeochannel fill sediments with up to 140cm of fine to medium sand in some cores (e.g. Core 17 Transect 4-Fig 6.10). Although the chronology of infilling cannot be fully ascertained from old maps, the only evidence for the former river channel on maps surveyed 70 years after abandonment (Fig 6.6C) is a small wetland area or oxbow lake (Section 6.1.1). This indicates significant infilling during the first 70 years following abandonment which corresponds with the extensive Sp facies.

Deposited on the outer meander bend of KW1 in transects 2, 3, 4 and 5 are medium sand and fine/medium sand infill sediments, facies Fl (e.g. Core 13 Transect 2-Fig 6.10), the vertical depth of which is variable due to original morphology of the channel and underlying Sp facies. The sediments contain fine sand lenses and laminations and display a sedimentation pattern that has maintained the channel form in the centre of the palaeochannels (Fig 6.10). The depositional environmental of facies Fl is interpreted as low energy flow through the channel, possibly during the final stages of flow through the channel following cut-off. The absence of similar sediments in transect 1 emphasises spatial variability in sedimentation of the facies.

Overlying facies Fl are shallow peaty silt and fine sand deposits, facies C (e.g. Core 16 Transect 1, Core 7 Transect 4-Fig 6.10) which have accumulated in the channel-like depressions formed by the underlying sediments. These sediments indicate a decoupling of the main channel and the palaeochannel, the accumulation of *in situ* organic material and a reduction in sedimentation rate. In transects 3, 4 and 5 the lower section of the organic facies is divided from the upper by a fine/medium sand horizon (e.g. Core 10 Transect 5, Core 14 Transect 3-Fig 6.10) most probably reflecting a large flood event. Facies C has developed in the depressions in underlying facies Sp and Fl and are only 0.7m at the deepest point (e.g. Transect 4, Core 7-Fig 6.10), and up to 0.2m only in transect 2. The period of *in situ* organic matter accumulation therefore appears to have been limited.

Beds of medium sand (e.g. Cores 20-36 Transect 3 Fig 6.10) and fine/medium sand form facies Sh (e.g. Core 10 Transect 5) and cover the underlying infill sediments of facies Sp, Fl and C in palaeochannel KW1. The sediments are laterally extensive through the palaeochannel and form layers of 10-30cm depth. The change in sedimentation patterns within the palaeochannel from facies C to Sh, including an increase in grain size and

reduction in organic matter, suggests a increase in sedimentation rate, possibly due to increases in overbank sedimentation or surface runoff, and associated reduction in vegetation cover.

Overlying the Sh facies is a thin (10-20cm deep) poorly developed top soil, facies P (Fig 6.10). The limited development of the soil, as observed from the soil structure and the limited soil horizon development, may relate to the age of the palaeochannel, only abandoned 200 years ago (Section 6.1). The facies characteristics may also reflect a continuation of overbank sedimentation as during contemporary high discharge events, the River Irthing is known to inundate the palaeochannel.

6.2.3 Plant macrofossils

A 100cm deep core (Table 6.5) extracted from palaeochannel KW1 (for location see Fig 6.8) was sampled at 0-5cm, 5-10cm depth and thereafter at 2cm intervals for plant macrofossil analysis. Loss on ignition values were obtained at each sampling interval (LOI Fig 6.12). The macrofossil stratigraphy has been divided into four zones (Fig 6.12) from a qualitative analysis of the results of the plant macrofossil analysis and species presence and patterns. The composition and interpretation of these zones are detailed below.

Table 6.5 Palaeochannel KW1 Plant Macrofossil Core Log

Depth	Transition (from above)	Description	Facies Code
0-23		organic medium brown fine sand, top soil	P-Sh
23-77	graded	peaty silty fine sand, frequent organic inclusions, small degree of humification	C
77-82	sharp	medium red brown fine sand, homogenous, no organic inclusions	palaeoflood
82-88	sharp	dark brown humified peaty silty fine sand, frequent organic inclusions	C
88-98	graded	as above, lighter colour less humification	C-Fl
98-100	graded	organic medium dark brown medium fine sand, few organic inclusions	Fl
100+	sharp	gravel	Gm

Macrofossil zone 1, between 100 and 84cm depth mainly comprises facies Fl grading into facies C up profile (Table 6.5). Macrofossils in the sediments at this depth include the aquatic species *Potamogeton* spp., evident throughout the zone, and *Alisma plantago-aquatica* which appears at 92cm depth. Caddis fly larvae and *Daphnia* ephippia were also present, both of

Figure 6.12

Kellwood Palaeochannel 1 Core Stratigraphy and Plant Macrofossils

which inhabit standing and slow moving water. The macrofossil record for zone 1 therefore suggests an aquatic environment, with little wetland habitat development. The distribution of aquatics within macrofossil zone 1 suggests that *Potamogeton* spp. was the first species to establish with *Alisma plantago-aquatica* following the first stages of terrestrialisation. The establishment of *A plantago-aquatica*, an emergent, in *Potamogeton* dominated communities following terrestrialisation and nutrient accumulation has been observed in contemporary aquatic communities (Rodwell 1995). Moreover, *A plantago-aquatica* is known to prefer mesotrophic or eutrophic conditions (Halliday 1997). The presence of *Juncus* spp. through Zone 1, a plant which rapidly establishes on newly formed surfaces (Grime *et al.* 1990), in the fossil record may reflect establishment either on the banks of the palaeochannel or on the exposed medium/coarse sand, deposited during abandonment.

The sedimentary characteristics of the macrofossil core reflect a high proportion of *ex situ* sediment deposition and limited organic matter accumulation. Up profile, lower energy inputs with a decreasing sedimentation rates are evident with the transition from facies Fl to C (Table 6.5, Fig 6.11) thus suggesting a reduction in the proportion of *ex situ* sediments and hence, plant macrofossils within the stratigraphy (cf. Abernethy & Willby 1999). The quantities values of organic matter within the core sediments are reflected by the loss on ignition values (Fig 6.12).

Macrofossil zone 2, from 84 to 70cm in depth, displays a marked change in the macrofossil record with an overall decline in the number of seeds and a loss of aquatic species (Fig 6.12). The organic matter within the core sediment rises to 72cm then declines (LOI Fig 6.12). Species present include ruderal and wide niche species including *Prunella vulgaris* and *Cerastium fontanum* as well as *Juncus* spp. and *Carex* spp. which exhibit an increasing presence up profile. The data suggest an initial limited vegetation cover with the development of a wetland habitat towards the top of the zone. The core sediments show a significant change in the characteristics of sedimentation at 82cm depth, with the input of red homogenous fine sand containing little organic matter (LOI Fig 6.12), that is interpreted as the deposit of a large flood (Table 6.5). This palaeoflood horizon is laterally extensive through transects 3, 4, and 5, (Fig 6.10) lying within the organic facies. The provenance of the flood sediment thus questions the taphonomy of the macrofossil remains. Zone 2 at the depth of the palaeoflood horizon, between 76 and 80cm depth, contains a number of ruderal and grassland species, such as *Prunella vulgaris*, *Cerastium fontanum*, and *Juncus* spp. which are found in meadow habitats and are tolerant of damp conditions and therefore it is possible that such species could have grown *in situ* with KW1. Bornette *et al.* (1998b) for example

found both *P vulgaris* and *Juncus* spp. in cut-off meanders of the River Ain, France. The former high energy inputs inferred by the sedimentary data and limited organic material however suggest that a high proportion of macrofossils between 82 and 77cm are *ex situ* in origin.

Macrofossil zone 3, which lies between 70 and 23cm depth, is dominated by *Daphnia* ephippia, *Alnus glutinosa*, and *Carex* spp., with a persistent presence of both *Potentilla palustris* and *Juncus* spp. (Fig 6.12). In addition, smaller numbers of wide niche species and grasses including *Leontodon autumnalis* and *Silene* spp are also present. The sediments within zone 3, correspond with the upper part of facies C, a period of low energy inputs and *in situ* organic matter accumulation (Fig 6.11). Zone 3 of KW1 displays a significant increase in the number of species within the fossil record of which many, including *Carex* spp. and *Potentilla palustris,* are wetland species. These indicate the development of a wetland habitat within the palaeochannel, typical of a sedge swamp environment. It is observed, however, that if the wetland was restricted to the area exhibiting a peaty silt substrate, the spatial extent of the habitat was limited to the depression towards the outer meander bend of KW1 (Fig 6.10). *Carex* spp. and *Potentilla palustris*, the persistent wetland species of zone 3, were found by Saarinen (1996) as dominants of a mesotrophic fen community. Wassen *et al.* (1990) also found *P. palustris* and *Carex* spp., as well as grasses in floodplain habitats characterised by low productivity and high water tables. Their presence, therefore, with other wetland, grassland and wide niche species in zone 3, implies a limited advancement in the trophic status of the habitat.

The presence of *Daphnia* ephippia within zone 3 signifies the persistence of standing water or periodic ponding within the palaeochannel. Cartographic evidence from the 1st edition OS map, surveyed c.1840 (Fig 6.6), shows the presence of a small body of water on the floodplain surface at the location of the former river channel, immediately downstream of the palaeochannel reach incorporated in KW1. Moreover, the sedimentation patterns in KW1 resulted in the persistence of a depression within the palaeochannel fill (Fig 6.10) which may have enabled periodic ponding. The *Alnus glutinosa* seeds in the fossil record indicate the presence of woodland, although the limited number of woody fragments or bud scales suggests that only a limited stand of trees lined the palaeochannel. The arboreal presence may explain the presence of *Leontodon autumnalis* and *Silene* spp., both of which are found in shaded locations (Grime *et al.* 1990). Overall, the composition of the macrofossil record and the sedimentary data result from a persistent high water table and limited eutrophication. Despite the limited trophic change in palaeochannel KW1, the development of the

palaeochannel community with fen vegetation replacing aquatic, infers the process of autogenic hydroseral succession.

The uppermost macrofossil zone, zone 4, of core KW1 extends from 23cm depth to the contemporary surface. Changes in the macrofossil record from zone 3 to 4 include a marked reduction in *Carex* spp., *Potentilla palustris* and *Alnus glutinosa* and an increase in wetland grasses (*Phalaris cf. arundinacea* and *Glyceria fluitans*), wide niche species (*Urtica dioica*) and grassland species (Fig 6.12). There is also a loss of aquatic species, therefore, zone 4 signifies the upper limit of the aquatic habitat within KW1. The zone corresponds with the Sh facies grading to the poorly developed top soil, facies P (Fig 6.11). The species which establish, include *Phalaris cf. arundinacea*, a wetland species that is toxic to sheep and occurs in drier parts of floodplain mires (Grime *et al.* 1991), *Urtica dioica,* a species found on fertile land and *Juncus* spp., the both of which are unaffected by grazing and *Glyceria fluitans*, a wetland species found in fertile mires (Grime *et al.* 1991). *P. arundinacea* and *G. fluitans* were found by Bornette *et al.* (1998a, 1998b) in frequently flooded meander cut-offs whereas the same researchers found *U. dioica* in isolated eutrophic palaeochannel habitats. There is also a persistent presence of *Stellaria media*, a species found in arable and fertile environments. The emergence and persistence of these plants and reduction in sedge swamp species suggest a change in the hydrological status or disturbance regime of the palaeochannel. Rodwell (1995) noted that livestock grazing in *Carex-Potentilla* sedge swamp areas could lead to the dominance of *Juncus* spp. Although macrofossil data cannot supply evidence as to the coverage of *Juncus* spp., its presence, the reduction of *Carex* and *Potentilla palustris* and the establishment of other grazing tolerant - nutrient loving species, suggests an increase in livestock grazing on the floodplain. In addition zone 4 corresponds with decrease of *in situ* organic matter accumulation (LOI Fig 6.12).

Overall there appears to be a number of potential explanations for the marked changes in both sedimentary and plant macrofossil data from zone 3 to zone 4. The sediments suggest a decrease in vegetation cover and increased overbank sedimentation of medium-fine sand facies Sh (Fig 6.11) while the macrofossil data infer increased grazing and changes to the palaeochannel nutrient levels. From contemporary observations it is known that during high discharge events KW1 is inundated, although the sediment load of the flow is unknown. Furthermore, the present habitat is heavily grazed by livestock which affects vegetation growth and increases the nutrient levels in the soil. The contemporary situation appears to reflect the conditions during the period of zone 4, the top 0.23m of the core. Therefore the

reason for the termination in vegetation succession and changes to the habitat characteristics can be attributed to the combined effects of flood inundation and agricultural activity.

6.3 *Results and Analysis for Palaeochannel KW2*

A 140m section of palaeochannel KW2, which encompassed the palaeochannel meander bend (Fig 6.1, Plate 6.2) was the subject of high resolution sediment coring and plant macrofossil analysis.

6.3.1 Palaeochannel geometry

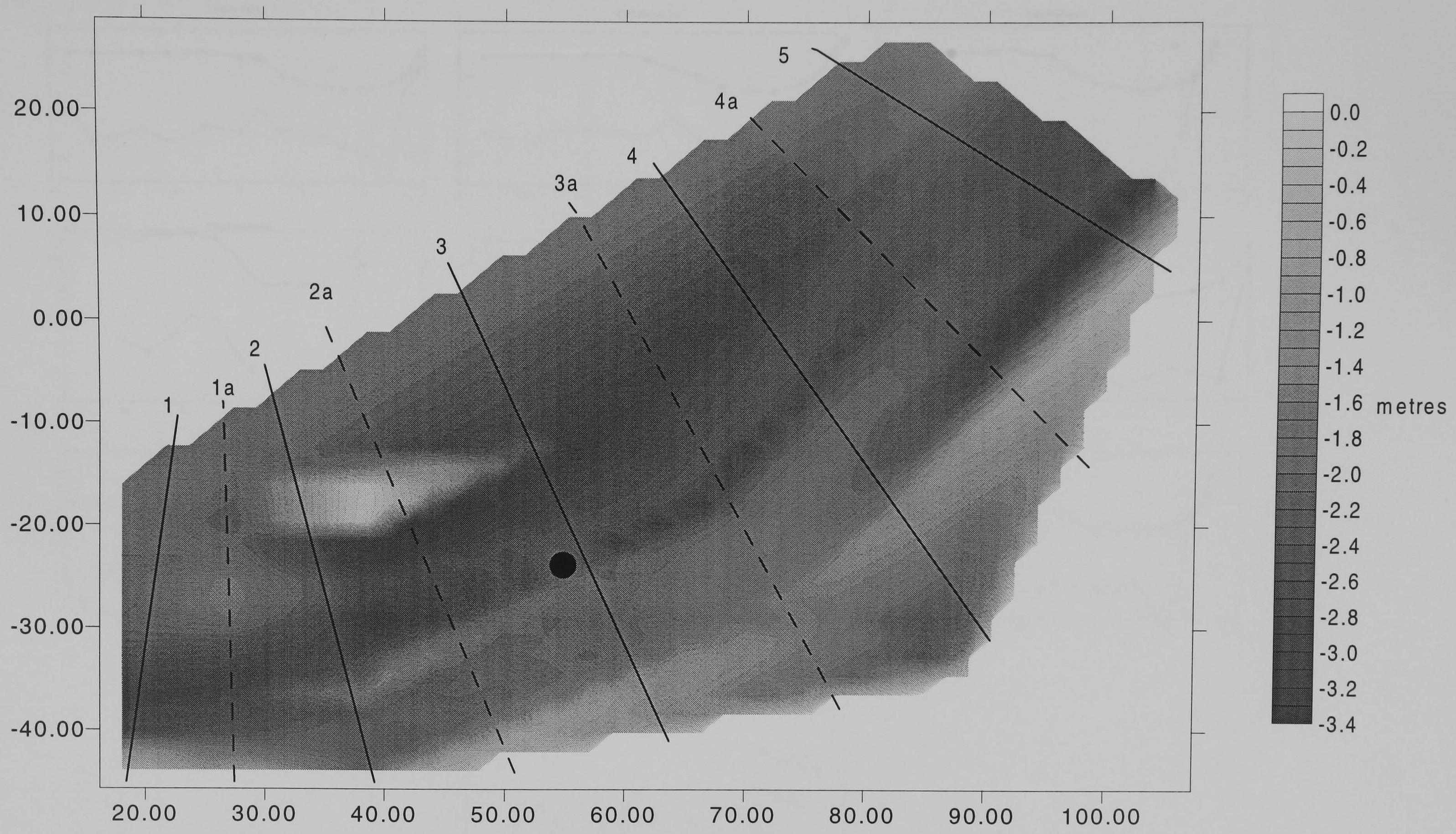
Nine transects along the 140m section of palaeochannel KW2 were cored at 2m intervals and at higher resolution to record change of slope where required, to ascertain the dimensions of the surface beneath the palaeochannel fill sediments (Fig 6.13 and 6.14). Each core location was surveyed (Fig 6.13). Equal spacing between all transects was attempted but not always possible due to the presence of features, such as trees, in and around the palaeochannel (Plate 6.2).

While the present surface of the palaeochannel resembles a well defined meander bend (Fig 6.1), the reconstructed former channel bed morphology has a variable morphology, with well defined steep outer banks although many of the channel cross section profiles (Fig 6.13), show parts of the former channel to have possessed a near symmetrical morphology. The inner, left bank of the channel is poorly defined. Transect 5, the furthest downstream, exhibits a gravel surface that deepens towards the right bank and is 0.5m deeper than the other transects. The steep gradient of the channel side, on the right side of palaeochannel KW2 indicates lateral erosion prior to abandonment. The palaeochannel is at the bottom of a steep terrace bluff which separates it from the high elevation (3m) late Pleistocene terrace (Fig 6.4). The depth of the palaeochannel thus reflects Holocene vertical channel incision into the valley floor.

Locally within palaeochannel KW2, basal medium/coarse sand alluvial sediments were found to directly overlie dark red homogenous coarse sand, which became very compacted with depth. This deposit was interpreted as weathered bedrock, Kirklinton Sandstone, the upper

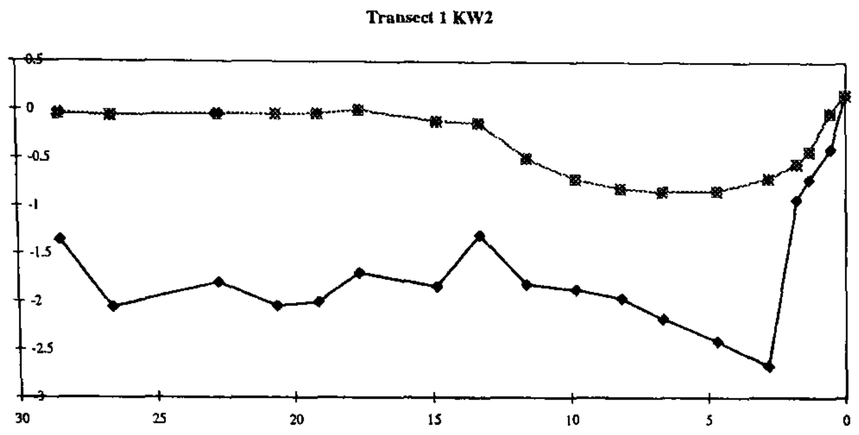
Kellwood Palaeochannel 2 (KW2) Gravel and Bedroack Surface Contours

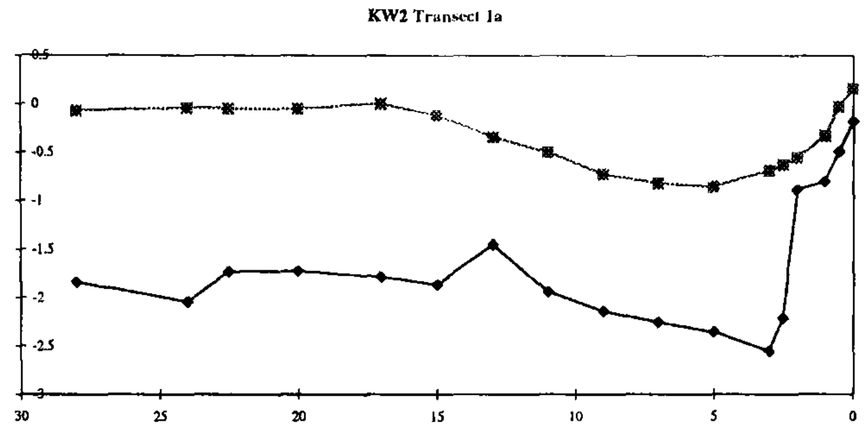
Figure 6.13

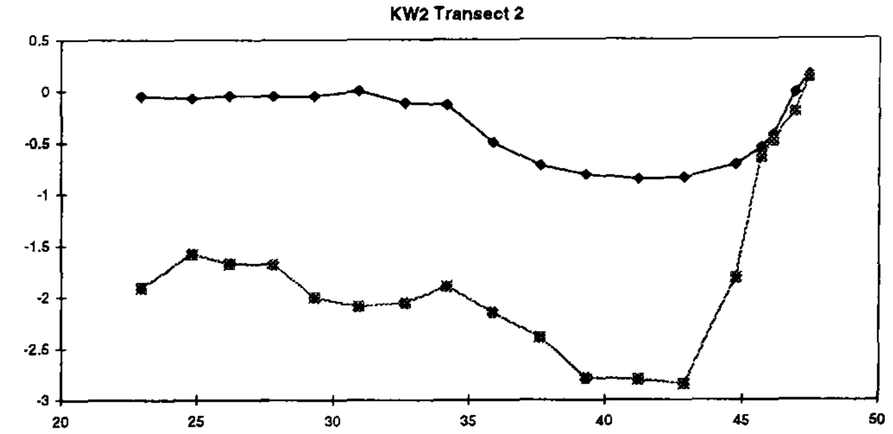


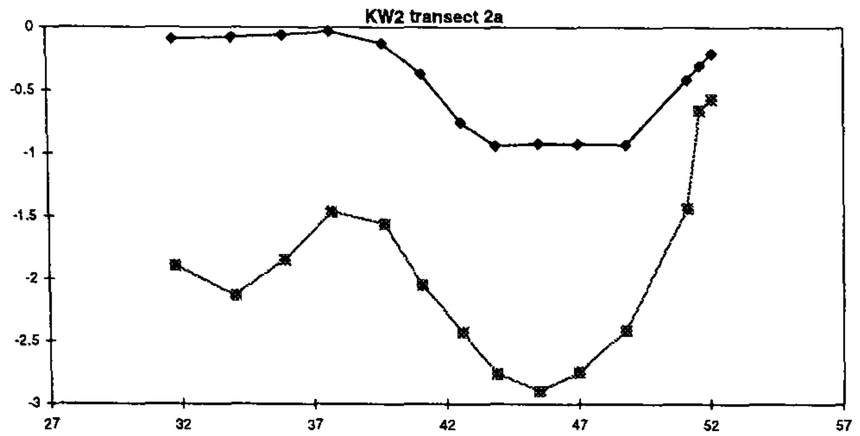
Kellwood Palaeochannel 2 (KW2) Gravel and Bed Rock Surface Cross Sections

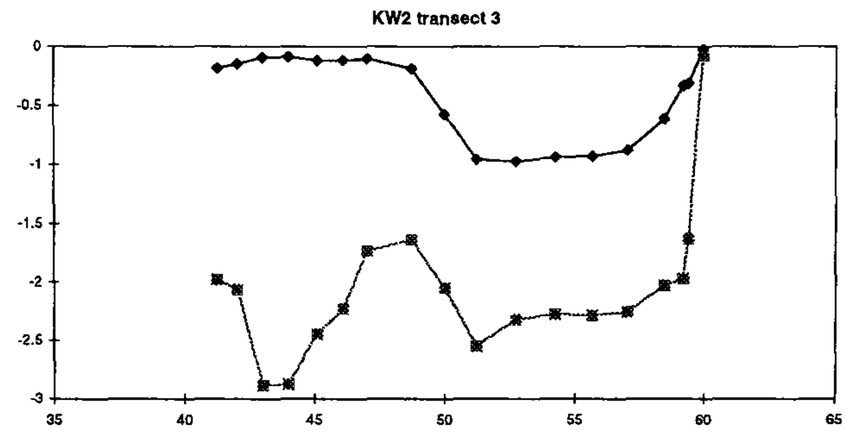
Figure 6.14

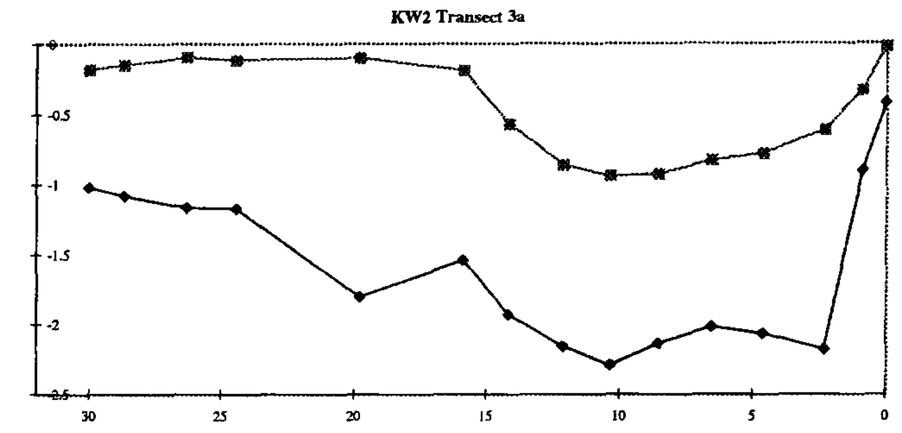


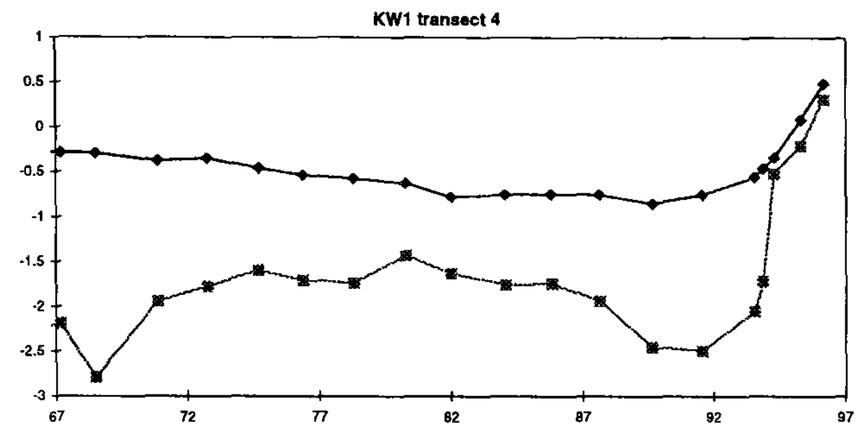


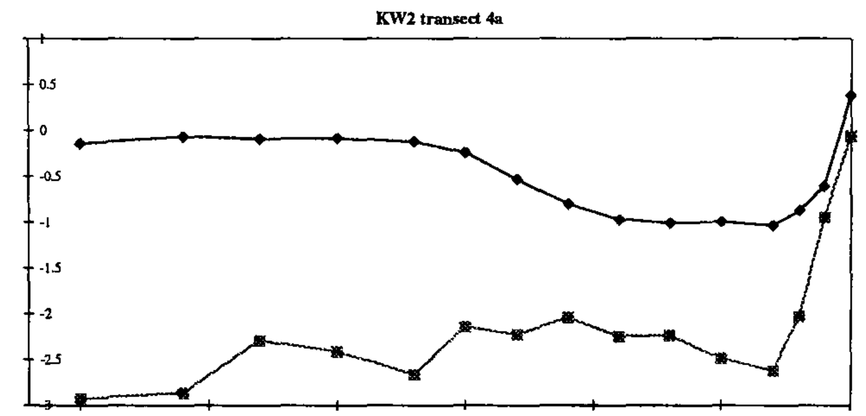


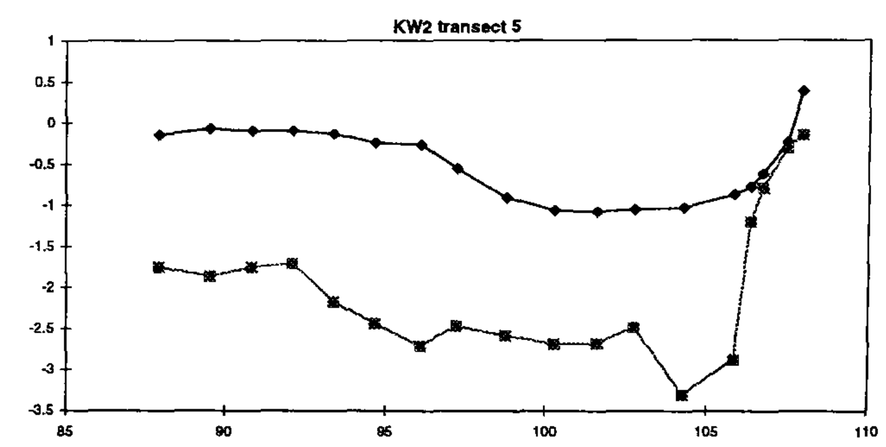


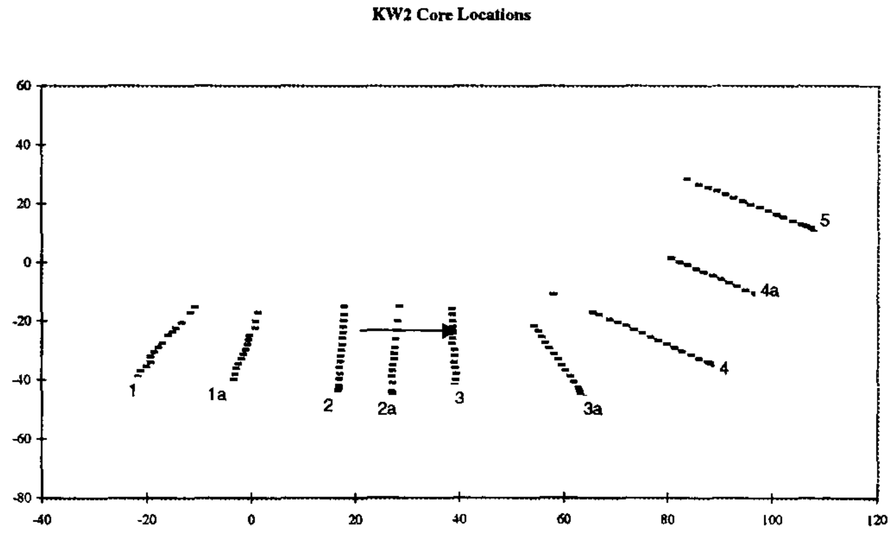












boundary of which will have formed the base of the former river channel, indicating that the river was incising into bedrock prior to abandonment.

With the exception of transect 5, the inner meander bend of the channel is poorly defined. To the middle of transects 1, 1a, 2a, 3, 4, and 4a, there is a small elevation in the channel bed, which may represent a mid channel bar form. The narrow channel on the left of the mid channel bar may have been a former chute channel or part of a more extensive multi-channel reach. Cartographic evidence of mid channel bars and of a planform which may be analogous with that of KW2, can be seen from the 1821/22 map of the River Irthing (see Fig 6.6B). Interpretation of the channel form is complicated by the extensive channel avulsions that characterise the floodplain evolution. From the valley floor morphology it is thought that the river may have reoccupied former courses during the Holocene (Section 6.1). It is possible, therefore, that morphological characteristics exhibited by the channel bed morphology may pre-date 670-970AD, the most recent period of channel abandonment. Overall, the form of KW2 depicts a complex reach with depositional features and evidence for a formerly wide active channel belt, of which only a proportion has been uncovered by sediment coring. The complexity of the former channel planform is not evident from the present surface morphology and thus was not noted during geomorphological mapping.

6.3.2 Lithostratigraphy of channel fills in palaeochannel KW2

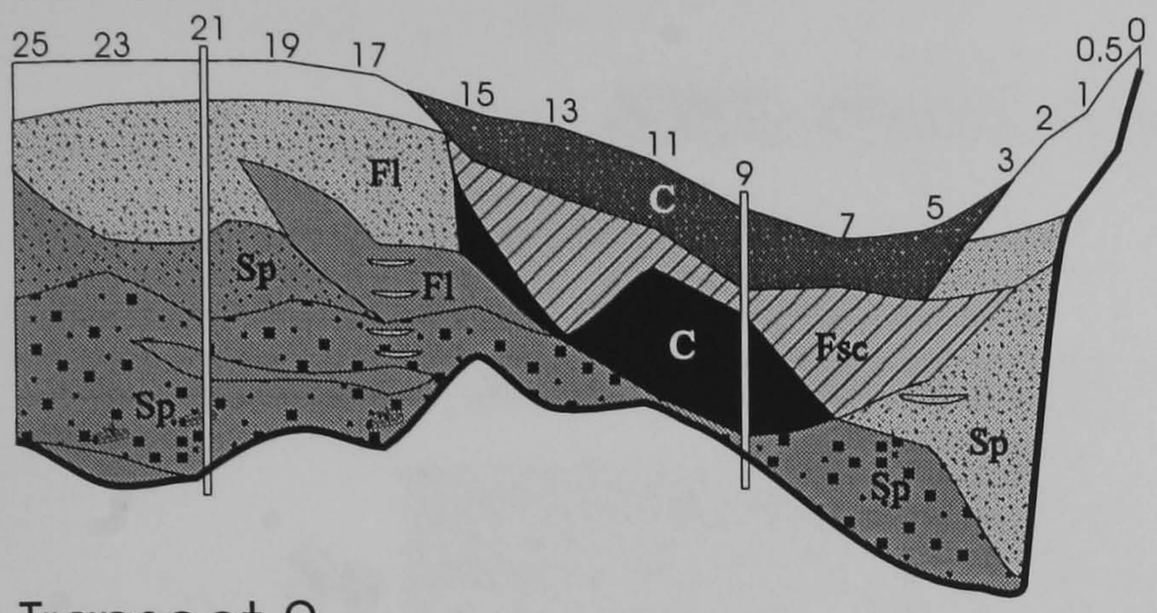
The results of the sediment coring for KW2 (Fig 6.15) are described and discussed below with transect 1 located at the upstream end and transect 5 the furthermost downstream. Using the lithofacies classification (Table 4.2) the fine grained palaeochannel fill sediments of KW2 have been divided into facies representing specific depositional environments. A temporal sequence of infilling is shown in Fig 6.15.

Medium/coarse and coarse sand deposits containing silt lenses and woody inclusions form facies Sp (e.g. Core 15 Transect 2, Core 17 Transect 5-Fig 6.15) and dominate the sediment fill of the inner meander bend, form inclined deposits and overlie the gravel and bedrock base of KW2. The sedimentation pattern reveals the persistence of a channel form, on the right channel side. The facies are interpreted as bed load, deposited during sustained flow through the channel. The sediments which infill the narrow channel feature on the inner meander bend may have been deposited prior to channel abandonment as a consequence of channel rationalisation. As the facies also forms the basal sediments in the main channel on the outer meander bend, which were probably deposited during channel abandonment, it is probable

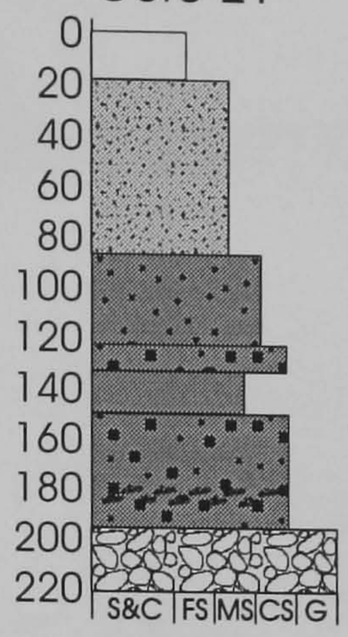
Kellwood Palaeochannel 2 (KW2) - Sedimentary Infills

Figure 6.15

Transect 1



Core 21



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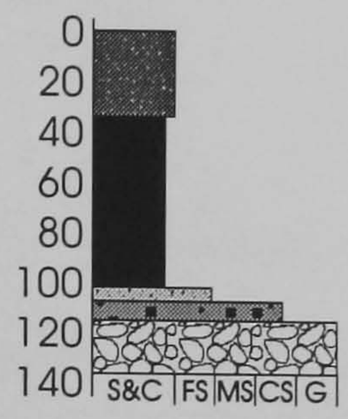
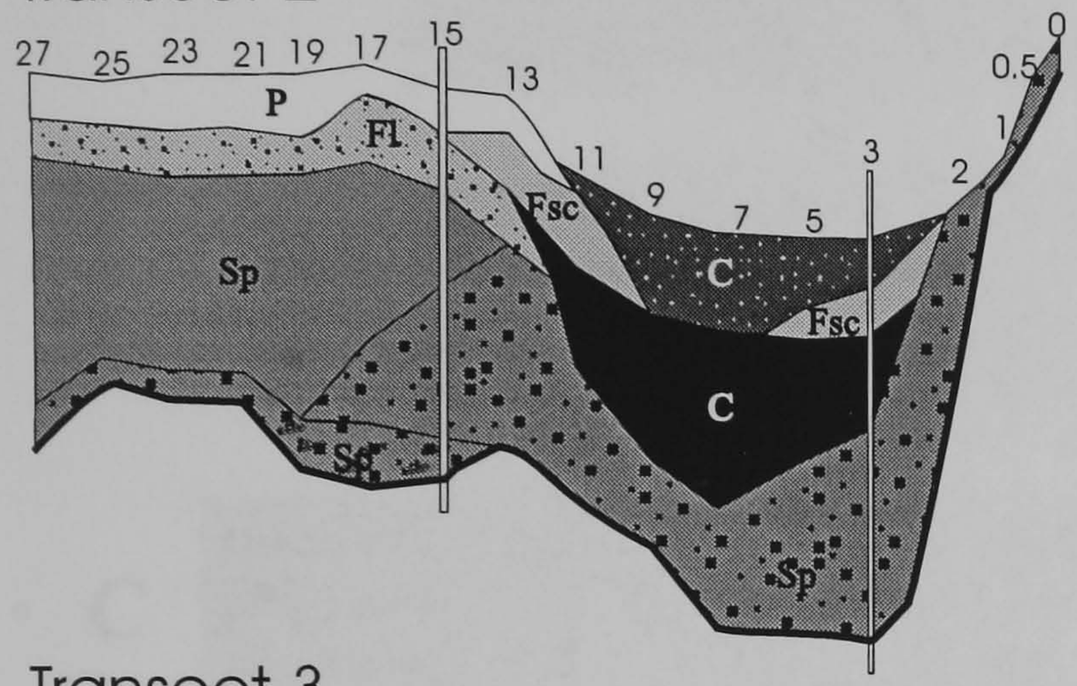
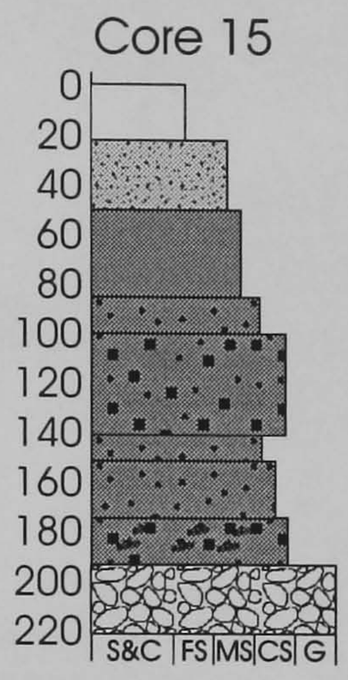


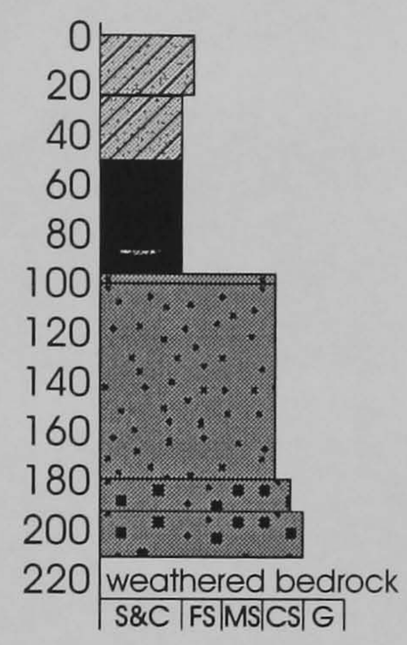
Transect 2



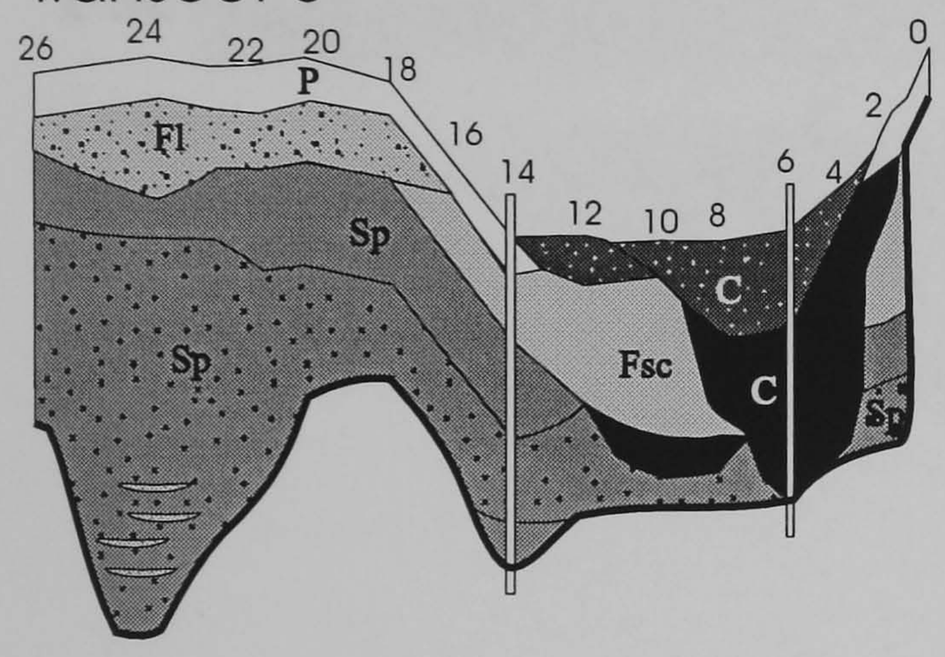
Core 15



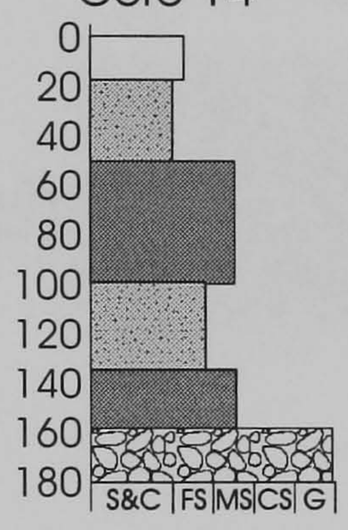
Core 3



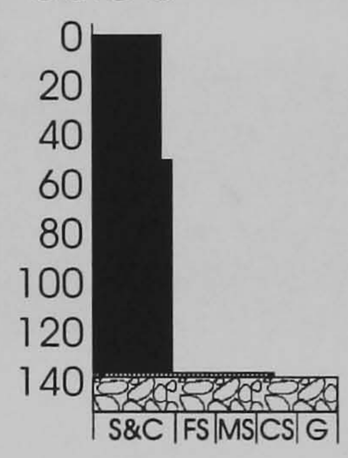
Transect 3



Core 14

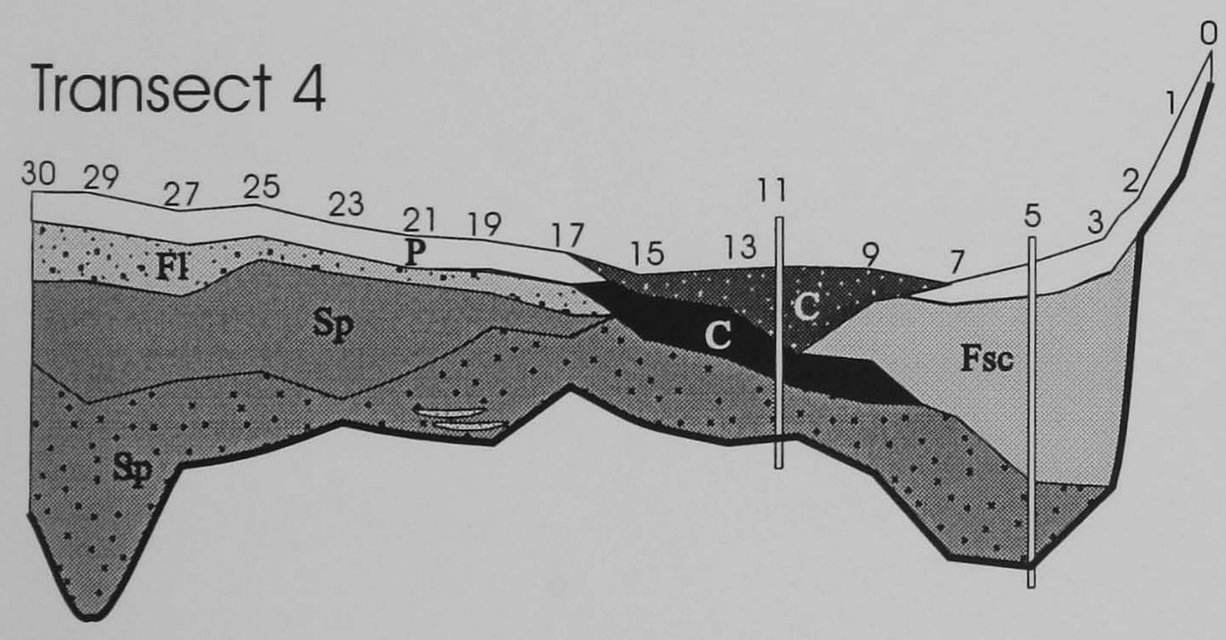


Core 6

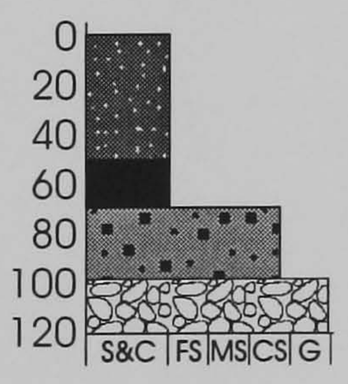


top soil
peaty silt
peaty fine sand
clayey silt
silts & fine sand
fine/medium sand
medium sand
medium/course sand
coarse sand
laminations
organic inclusions
lenses
woody inclusions
gravel
Sp facies
7 9 core locations
gravel and bedrock

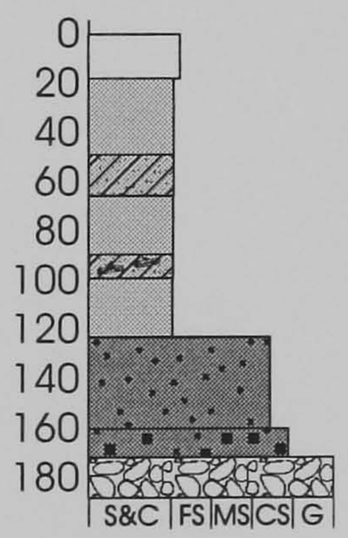
Transect 4



Core 11

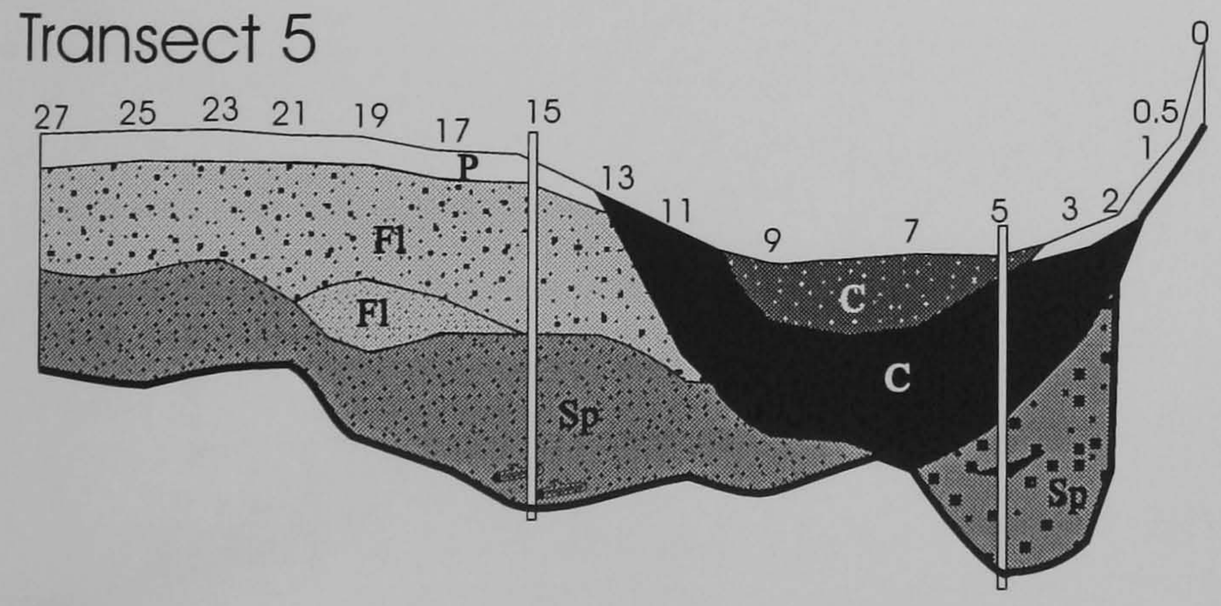


Core 5

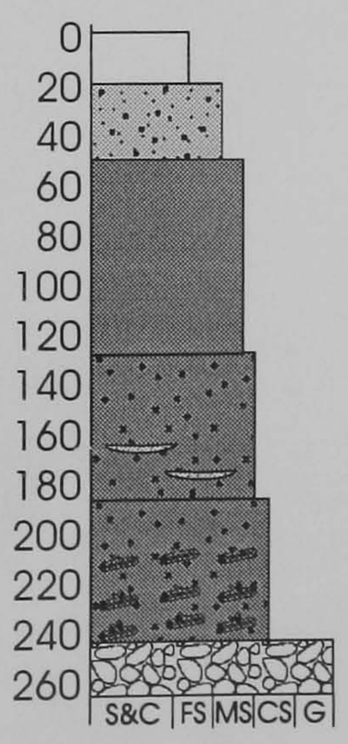


1m
0.5
0
0
5m

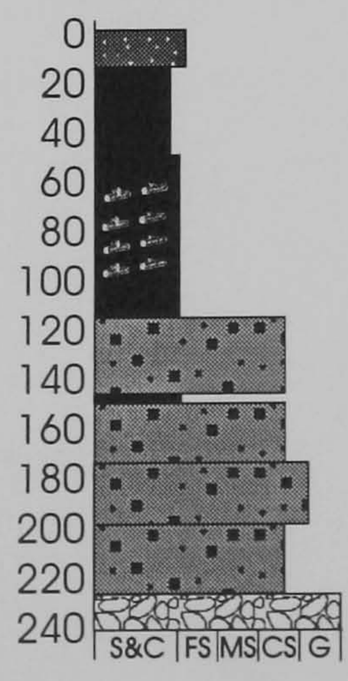
Transect 5



Core 17



Core 5

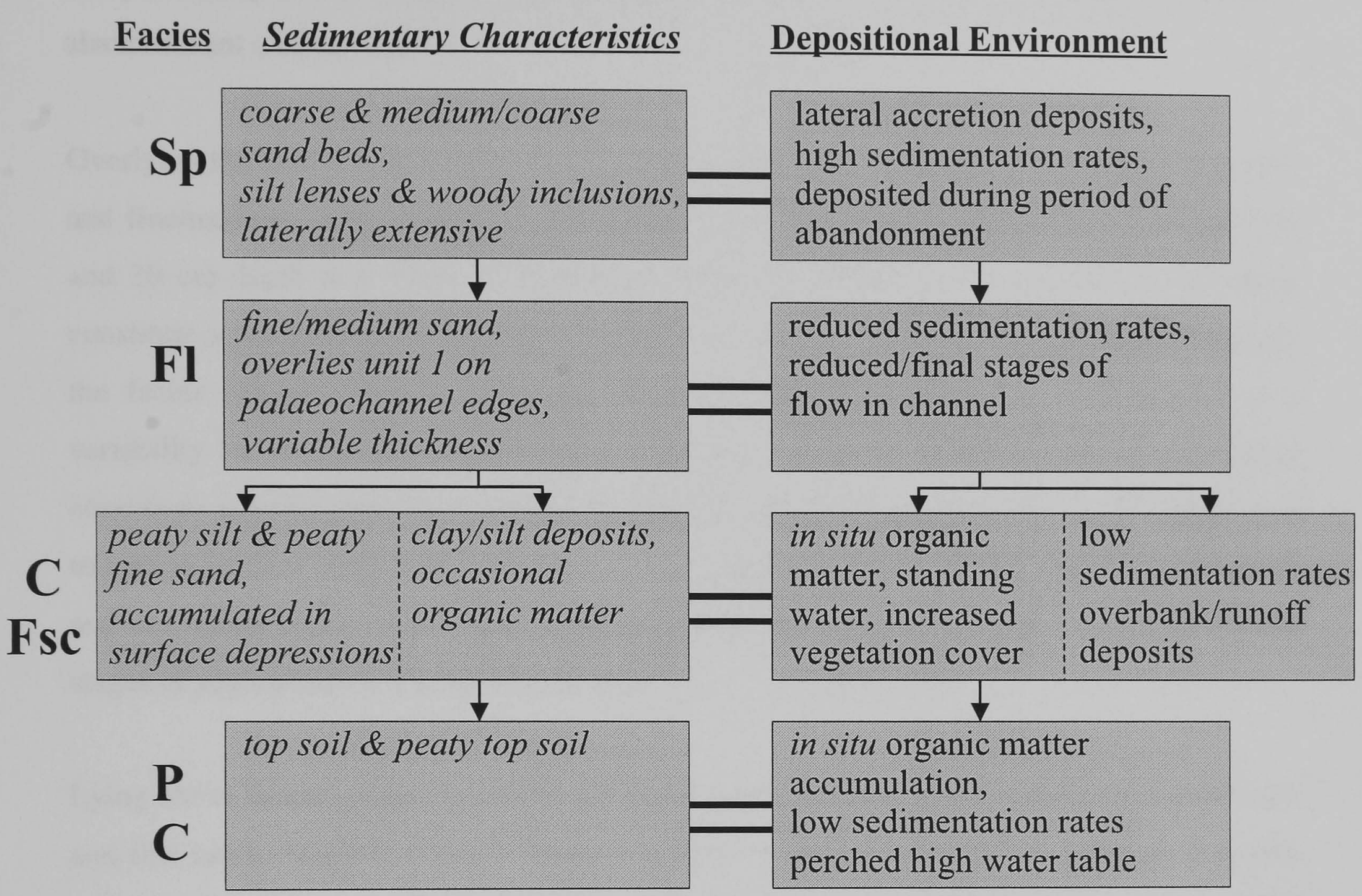


Left Channel Side

Right Channel Side

Figure 6.16

KW2 - Model of Sedimentary Deposition



that facies Sp comprise both infill and abandonment deposits. A degree of normal gradation, fining upwards, is evident within the facies which is related to declining flow velocities or sediment supply. The facies constitute a large proportion of the palaeochannel sedimentary fill, potentially due to a large sediment supply within the system or the character of channel abandonment (Allen 1965).

Overlying the medium and coarse sands, mainly on the left bank of the channel, are medium and fine/medium sands, facies Fl, which form a laterally extensive horizon of between 100 and 30 cm depth (e.g. Core 17 Transect 5, Core 15 Transect 2-Fig 6.15). The sediments constitute a progressive fining sequence from the underlying Sp facies (Fig 6.16). Although the facies extends laterally along the length of palaeochannel fill sediments there is a variability in its depth, corresponding with and, therefore, dictated by the antecedent conditions (surface elevation) created by the underlying fill sediments. Facies Fl represent a reduction in flow velocities, sedimentation rate and, possibly, sediment supply to the reach and are interpreted as the overbank deposits following channel rationalisation and the late stages of sedimentation during abandonment.

Lying above facies groups Sp and Fl are fine grained infill sediments, comprising peaty silts and fine sands, facies C (Core 5 Transect 5, Core 6 Transect 3-Fig 6.15) and clays and silts with organic inclusions, facies Fsc (Core 5 Transect 4-Fig 6.15). Both sediment types infill the surface depressions created by underlying sediment along the palaeochannel reach but have been divided into two lithofacies types, separated on the basis of sedimentary characteristics but representative of similar depositional environments. The peaty silts and peaty fine sands, facies C, indicate an increased vegetation cover and *in situ* organic matter accumulation. Facies C is locally exposed where it extends up to the present palaeochannel surface (Core 6 Transect 3-Fig 6.14). The second sedimentary deposits, facies Fsc form clays and silts with organic horizons. The facies reflects a low sedimentation rate but less in situ organic matter accumulation than facies C and hence a less extensive vegetation cover.

Top soil, facies P, has developed over the Fl facies on the left palaeochannel side (Core 15 Transect 2-Fig 6.15) while the topographical lows in the middle of the palaeochannel exhibit peaty fine sand facies C at the surface. The top soil forms the uppermost facies, P, covering the higher terrace surface of KW2. The persistent high water table which enables the accumulation of organic matter may result from the impermeability of the underlying C facies forming a perched water table (Brown 1997a), but also from the position of the

palaeochannel reach at the bottom of the Pleistocene terrace (Fig 6.4) making it the point of accumulation for runoff and groundwater inputs from the valley sides.

6.3.3 Plant macrofossils

A 110cm deep core (Table 6.6) extracted from palaeochannel KW2 (for location see Fig 6.13) was sampled at 2cm intervals throughout the whole core for plant macrofossil analysis. Loss on ignition values were obtained for each sample interval (LOI Fig 6.17). The macrofossil stratigraphy has been divided into four zones (Fig 6.17) from a qualitative analysis of the plant macrofossil results and species presence and patterns. The composition and interpretation of these zones is described below.

Table 6.6 Palaeochannel KW2 Plant Macrofossil Core Log

Depth	Transition (from above)	Description	Facies Code
0-19		dark brown peaty fine sandy silt. Root penetration and organic inclusions, some structure (slightly friable)	C
19-31	graded	medium grey brown fine sandy silt, some woody and plant organic inclusions, large wood fragment at 22cm, little structure, some manganese nodules	C
31-44	graded	light grey brown clayey fine sandy silt, few organic inclusions, little structure evident, some fine root penetration.	Fsc
44-48	graded	as above, fewer organic inclusions, no root penetration, homogenous	Fsc
48-50	graded	medium grey brown peaty silt, large organic inclusions, debris layer	C
50-56	graded	homogenous silt, little organic content, light grey brown.	Fsc
56-66	graded	medium grey brown fine sandy silt, lots of woody inclusions, structureless.	C
66-88	graded	peaty fine sandy silt, darker than above, lots of woody inclusions, inclusions decrease with depth, some humification.	C
88-101	graded	dark grey brown silty fine sand, few organic inclusions, occasional coarse/medium sandy lenses.	Fl
101-110	graded	medium brown coarse medium sand, occasional silty fine sand lenses and organics, large wood fragment 106-110cm.	Sp

The oldest macrofossil zone at the bottom of the core dating to *circa* 670-970cal.AD within KW2 extends from 110 to 77cm depth and is dominated by high numbers of *Juncus* spp., *Cerastium fontanum, Callitriche* spp. and *Glyceria fluitans* seeds. Lower numbers of Poaceae, *Ranunculus repens*, *Alisma plantago-aquatica, Epilobium palustre*, and *Scirpus setaceus* alongside ruderals and wide niche species are also present. A general view of the palaeochannel as depicted by macrofossil zone 1, therefore, is of aquatic and wetland habitats with a moderate species richness. The sedimentary conditions within the zone extend from

Kellwood Palaeochannel 2 Core Stratigraphy and Plant Macrofossils

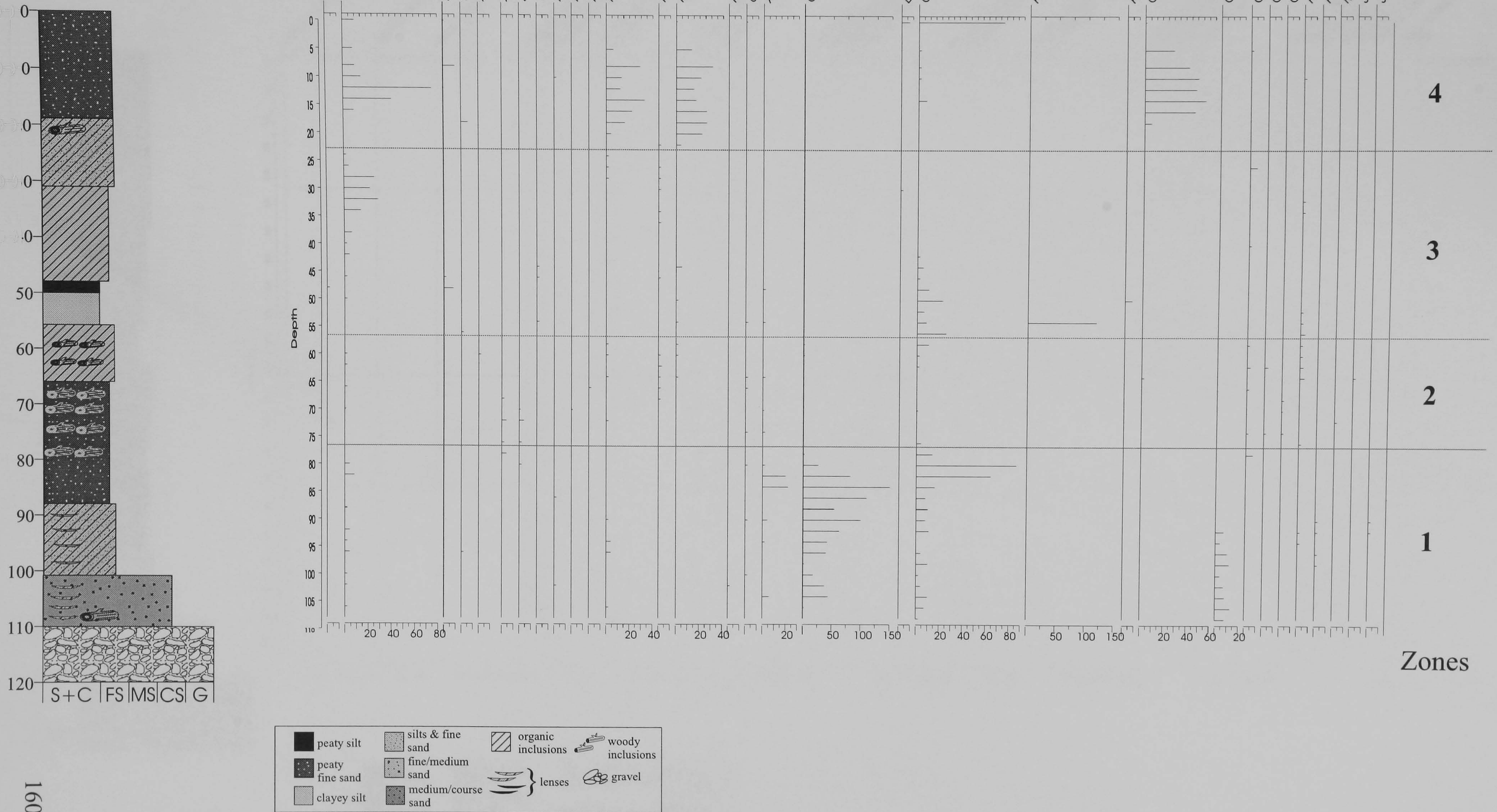
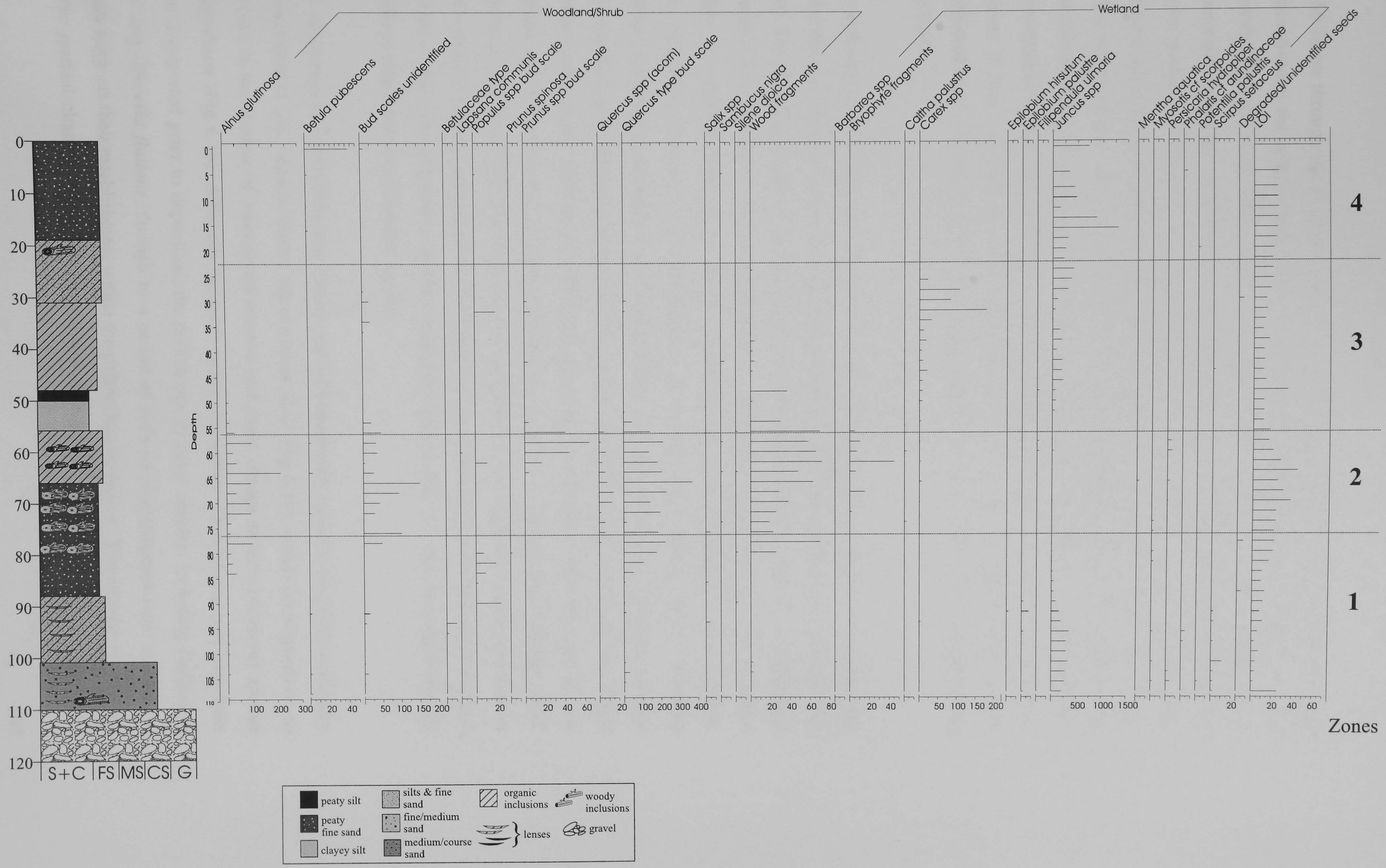


Figure 6.17b

Kellwood Palaeochannel 2 Core Stratigraphy and Plant Macrofossils



the Sp facies through the Fl to the lower facies C deposits (Table 6.6, Fig 6.16). Persistent species through the zone include *Glyceria fluitans*, frequently found by flowing rivers and wetlands (Bornette *et al.* 1994a, 1994d), *Callitriche* spp., a genus found to be dominant in occasionally inundated oxbow lakes on the River Rhiedol floodplain (Jones 1956) and *Scirpus setaceus*, a species found on eroding river banks (Grime *et al.* 1990). *Cerastium fontanum* and *Epilobium palustre*, although possessing variable habitat niches, are both found to flourish in *Juncus* spp. flushes in the Cumbrian region (Halliday 1997), therefore the persistent presence of all three within zone 1 suggests their establishment proximal to the palaeochannel. *Juncus* spp. is known to be one of the first genus to establish on bare soil, however it does not germinate underwater (Grime *et al.* 1990). It is more likely to have established on the extensive area of bare sand, created during the deposition of the Sp facies (Fig 6.14).

The sedimentary conditions for the zone consist of facies Sp up to 88cm, representing the period during which the palaeochannel maintained its connection with the active channel (Fig 6.16). The upper sediments of macrofossil zone 1 correspond with the facies Fl representing a reduction in sedimentation rate and, potentially, a reduction in flow velocities and sediment supply. The sediments therefore indicate a habitat in which riverine plants would establish. The combined macrofossil and sedimentary data for the lower part of zone 1 therefore indicates a channel containing slow flowing water, with riverine species lining the channel and a rapidly establishing wetland community on the sand bars on the left channel side. There remains however the problem of taphonomic processes as the active channel, even if slow flowing, infers the presence of extra-local organic material (cf. Abernethy & Willby 1999, Amoros & Bornette 1999). Furthermore, loss on ignition values indicate a low proportion of *in situ* organic matter accumulation (LOI Fig 6.17). The macrofossil record for the lower part of zone 1 therefore potentially denotes a riverine community, but may also represent the results of allochthonous propagule inputs.

The upper part of macrofossil zone 1 forms part of sedimentary facies C, (Fig 6.15) indicative of increased *in situ* organic matter accumulation (LOI Fig 6.17), which corresponds to an increase in the number of macrofossil remains and slight change in the macrofossil species composition (Fig 6.16). Although the seeds within the lowest 20cm of the core may have been transported prior to deposition, the persistence of some species, including *Callitriche* spp. and *Glyceria fluitans,* through to a period of reduced sedimentation rates and fluvial inputs suggests their establishment within the palaeochannel habitat. Towards the top of zone 1, the gradual changes in the macrofossil record include an increase in *Alisma plantago-*

aquatica, *Populus* spp. and *Salix* spp. The increased presence of *A. plantago-aquatica* infers the accumulation of nutrients (Bornette *et al.* 1994a) in the aquatic habitat of palaeochannel KW2. The establishment of *Populus* spp. and *Salix* spp. is a common phenomena in alluvial environments. *Populus* spp. has a high growth rate (Walker *et al.* 1986) and is known to rapidly establish with *Salix* spp. and *Alnus* spp., in areas of high sedimentation (Nanson & Beach 1977). Furthermore, *Populus* and *Salix* have been frequently found on coarse sediments and next to channels and side arms on the River Drac floodplain (Pautou *et al.* 1997). Therefore, their presence in KW2 suggests the development of scrubland/thicket type vegetation (*sensu* Pautou *et al.* 1997) on the elevated surface next to the former channel (Fig 6.15).

Macrofossil zone 2, between 77 and 57cm depth, displays a marked change in species presence, with large numbers of woody species remains, including seeds, fruits and bud scales of *Alnus glutinosa, Quercus* spp., *Prunus* spp. and *Sambucus nigra* (Fig 6.17). Lower numbers of wetland, ruderal and wide niche species including *Caltha palustris, Filipendula ulmaria, Cirsium* spp., *Myosotis scorpioides* and *Urtica dioica* also maintained a persistent present through the zone. The macrofossil record therefore depicts a wetland-woodland habitat. The macrofossil zone corresponds with sediment facies C (Table 6.6) and a progressive increase in the proportions of organic matter in the core up to 62cm depth (LOI Fig 6.17). The initial change in the composition of the macrofossil record from zone 1 to 2, occurs around 77 to 80cm depth (Fig 6.17), with a reduction in aquatic species and establishment of more woodland species (following *Populus* and *Salix* in macrofossil zone 1). *Prunus* spp. (including *Prunus spinosa*) and *Sambucus nigra* are both common to lower canopy shrub communities in contemporary British floodplains (Harper *et al.* 1997). *Alnus glutinosa* and *Quercus* spp. replaced *Salix* and *Populus* communities on the River Drac floodplain following the accumulation of biomass (Pautou & Decamps 1985) and consequent changes to the substrate and nutrient characteristics of the habitat. Furthermore, environmental conditions associated with the presence of *Quercus* spp. on floodplain surfaces include fine substrates and elevations above the active floodplain (Hupp & Osterkamp 1985, Hupp & Simon 1991).

The sedimentary conditions for macrofossil zone 2 reflect a reduction in sedimentation rate and increased *in situ* organic matter accumulation. The persistently high water table evidenced by the palaeochannel sediments suggests however that conditions within the former channel would not have been suitable for woodland species (cf. Pautou *et al.* 1997. Robertson & Augspurger 1999), whereas the terrace surface on the left channel side would

have provided a more suitable habitat. As discussed above, the elevated surface formed by the deposition of facies Sp and Fl on the inner meander bend (Fig 6.15) enabled the development of scrubland/thicket type vegetation, which would have instigated the accumulation of a thin soil cover and increased the nutrient levels, rendering the area suitable for woodland establishment.

Other species within macrofossil zone 2, including wetland species (*Persicaria hydropiper*, *Filipendula ulmaria* and *Caltha palustris*) as well as ruderal and wide niche species are interpreted as comprising the sub-communities beneath the wooded terrace surface and the habitat within the palaeochannel itself. *Filipendula ulmaria* and *Caltha palustris,* as well as *Mentha aquatica* which also has a small presence in zone 2, are found in habitats where dominants are restricted due to shade or nutrient stress (Grime *et al.* 1990). As the high number of woody remains in the macrofossil record suggests arboreal species are overhanging KW2, the presence of these wetland species may be a consequence of canopy creation following woodland development on the terrace surface.

The increase in numbers of arboreal remains coincides with decreases in certain wetland species (e.g. *Juncus* spp., *Scirpus setaceus, Epilobium palustre*) and aquatic species (e.g. *Callitriche* spp., *Glyceria fluitans*). The reason for the decline may relate to a number of environmental factors, including changes in hydrological conditions, nutrient values, substrate and shade (Van der Valk 1981). The data from zone 2 suggest terrestrialisation within the palaeochannel which, alongside increases in organic sediments and the aforementioned creation of shaded conditions rendered conditions unsuitable for some pioneer species. Conversely, if the macrofossils within zone 1 were transported and deposited from upstream within abandonment deposits (e.g. facies Sp) their reduction may correlate with the decoupling of the palaeochannel from the active channel during macrofossil zone 2. Overall, the changes within KW2 from macrofossil zone 1 to zone 2 are two-fold. Firstly, the macrofossil data show the development of a woodland community on the terrace surface, with a shrub sub-community. Secondly, within the former channel, stabilisation, trophic changes, terrestrialisation and a canopy cover result in a loss of aquatic species and significant changes to the composition of the wetland community. Pautou & Decamps (1985) referred to the development of *Quercus* and *Alnus* type communities on terrace surfaces as the result of allogenic succession relating to initial high sedimentation rates creating floodplain surfaces suitable for woodland establishment. This type of vegetation succession is also evident from the macrofossil data of KW2.

The macrofossil record of zone 3, from 57 to 23cm depth, shows a decline in woodland species followed by the establishment of *Carex* spp.. There is also a recurrence of *Juncus* spp., *Glyceria fluitans* and Poaceae and the presence of the aquatics *Potamogeton* spp. and *Plumatella* (Fig 6.17). The loss of the woodland species has a number of implications. It implies a change in environmental conditions, such as significant changes in hydrology or climate or accelerated human activity, with the possibility of deforestation. The change to the vegetation community of the terrace associated with KW2, may also have effected a change to the palaeochannel vegetation composition which, as showed in macrofossil zone 2, was highly influenced by the presence of a woodland canopy.

The sedimentary facies of zone 3 comprise facies Fsc (Fig 6.15) signifying a degree of suspended sediment deposition (cf. Gurnell 1997) while loss on ignition values indicate a decline in organic matter (LOI Fig 6.17). Moreover, the macrofossil core comprises a highly organic layer at 49cm depth which resembles a debris layer of 2cm depth (Table 6.6). The initial slight reduction in organic material depicts a reduced vegetation cover or increase in sedimentation rates whereas, the debris layer represents the possible input of allochthonous material. The presence of *ex situ* material or increased waterlogging may explain the anomalous presence of *Plumatella*, a limnic fauna (Birks 2000) and the aquatic plant *Potamogeton* spp. The debris layer may also reflect the dying, cutting or destruction of palaeochannel and terrace vegetation. The remaining sediment within zone 3 contains increasing volumes of organic material (LOI Fig 6.17) suggesting a return of a more extensive vegetation cover or the reduction in sedimentation rates.

The decline in woodland species presence revealed by the macrofossil record in zone 3 corresponds with increases in *Glyceria fluitans*, *Galeopsis tetrahit* and *Rumex obtusifolia*. The first species signifies a wetland or flowing water habitat, whilst the latter two are representative of disturbed, often damp, ground (Grime *et al.* 1990). The change therefore suggests possible disturbance with a persistent high water table within the palaeochannel. These primary changes are followed by the establishment and return of *Juncus* spp., *Carex* spp., and Poaceae. *Juncus* spp. rapidly establishes on exposed soil and its presence and that of Poaceae may represent the change in vegetation on the terrace surface and within the palaeochannel. The presence of *Carex* spp. coincides with the increase in organic content and hence nutrient levels in the sediments, inferring the development of a sedge swamp type community in palaeochannel KW2 (Rodwell 1995).

Overall, the changes in the macrofossil record between zones 2 and 3 reveal a marked change in vegetation communities with the decline of woodland vegetation due to either a shift in environmental conditions or human activity. Towards the top of the zone, the development of a sedge swamp type habitat occurs and the corresponding establishment of reeds and grasses in and around the palaeochannel and terrace. The latter change in vegetation community composition suggests the process of autogenic succession with the transition from wetland grasses and low vegetation cover to an increase in vegetation cover, change in nutrient status and the development of a sedge swamp (cf. Pautou & Decamps 1985, Amoros & Wade 1996).

Macrofossil zone 4 of palaeochannel KW2, extends from 23cm depth to the contemporary palaeochannel surface. The macrofossil record shows the near complete absence of woodland species with a drop in *Carex* spp seeds and achenes. *Juncus* spp. seeds dominate the zone with up to 1500 seeds found in one layer. High numbers of Poaceae, *Cerastium arvense, Rumex obtusifolia* and *Ranunculus repens* seeds are also evident, with the occasional appearance of *Stellaria media, Rumex acetosa, Glyceria fluitans, Daphnia* ephippia and *Phalaris cf. arundinaceae* inferring an open, wet grassland habitat. The sedimentary conditions of the zone correspond with soil, facies P and organic facies C which extend to the surface, indicating waterlogged conditions and *in situ* organic matter accumulation.

The macrofossil data infer an end to the short lived successional trend seen within zone 3. The species present represent a wetland and wet meadow environment. Species including *Cerastium fontanum, Stellaria media* and *Rumex acetosa* can all be found in damp environments but also thrive on fertile ground (Grime *et al.* 1990). Furthermore, both *Rumex obtusifolia* and *Ranunculus repens* can survive grazing and periodic mowing (Grime *et al.* 1990). The present palaeochannel habitat is dominated by *Juncus* spp. and waterlogged for most of the year. There is no evidence for any influence of the main channel with the waterlogging resulting from the perched water table (Brown 1997a) formed by the impermeable silt and clay channel fills and the position of KW2 at the bottom of a terrace bluff (Plate 6.2). Therefore, the macrofossil record and sedimentary data of zone 4 appear to reflect the present habitat and the change in habitat composition is interpreted as resulting from accelerated agricultural activity.

Plate 6.1 Sediment coring along a transect of KW1

Plate 6.1 KW2 palaeochannel contemporary vegetation community

Chapter 7

Overview: Ecological Change on the River Irthing Floodplain with Respect to Holocene Valley Floor Development

7.1 Holocene Development of the River Irthing Floodplain in the Context of Upland River Catchments in Northern England and Southern Scotland

Section 7.1 describes the alluvial history of the extended study reach of the River Irthing whereby valley floor development described in Sections 5.1 and 6.1 is synthesised with published data of British upland valley floor development, with specific reference to periods of alluviation and incision. This synthesis will allow an evaluation and contextualisation of the timing and character of fluvial activity along the extended reach of the River Irthing. Valley floor development is also discussed in the context of proxy climatic change records and archaeological and palaeoecological records of human activity in the River Irthing catchment to assess possible correlation between the chronology of fluvial activity and environmental change. The character, chronology and potential controls of valley floor evolution will provide a template for the high resolution reconstruction of the five palaeochannel reaches (Section 7.2).

Figure 7.1 is a summary diagram which illustrates the Holocene alluvial history of the extended study reach along the River Irthing floodplain in comparison with published records of dated alluvial sediments, proxy climate change and records of human activity. Episodes of alluviation and incision at seven upland and middle reach sites in northern England are represented on Figure 7.1. Each of these sites has been discussed in Chapter 2. Periods of climatic deterioration are also represented on Figure 7.1. The data derive from proxy climatic records obtained from ombrotrophic bogs in northern England. Climatic deterioration from these records is determined from palaeoecological data reflecting increased surface wetness, resulting from increases in effective precipitation (Barber *et al.* 1994a, Mauquoy & Barber 1999a). The proxy climate records include data from Bolton Fell Moss and Walton Moss which are located within the River Irthing catchment, four kilometres from the study reach.

Only the fluvial terraces at the Dovecote and Kellwood reaches are illustrated on Figure 7.1 as no dating control is available for the terrace units at Breconhill. The diagram shows the height above the present active river bed and the timing of incision and palaeochannel

infilling. As no direct dating was obtained for terraces T2 and T3 at Dovecote (Fig 5.6), their chronology is approximated to the early to mid Holocene. The timing of abandonment of palaeochannel DC2 provides a *terminus post quem* for associated terrace T4 (Fig 5.1). Similarly, the infilling of palaeochannel KW2 *circa* 670-970cal.AD determines the *terminus post quem* for the older of the two Holocene fluvial terraces at Kellwood (T2-Fig 6.1). The abandonment of palaeochannel DC4 *circa* 1410-1620cal.AD provides a chronology for the alluviation of mid to late Holocene terraces at Dovecote (Fig 5.6). Periods of incision following channel abandonment during the eighteenth and nineteenth centuries (Fig 5.7 and 6.6) are also illustrated. It is acknowledged that wide error margins are present within the alluvial history chronology due to the age span gap provided by radiocarbon dating. Furthermore, it is possible that overlap between periods of channel incision and terrace alluviation exists. Therefore processes of valley floor evolution are not as distinct as suggested in Figure 7.1.

Figure 7.1 Summary diagram of Holocene alluvial units and alluvial and incision episodes for the River Irthing and selected upland British catchments.

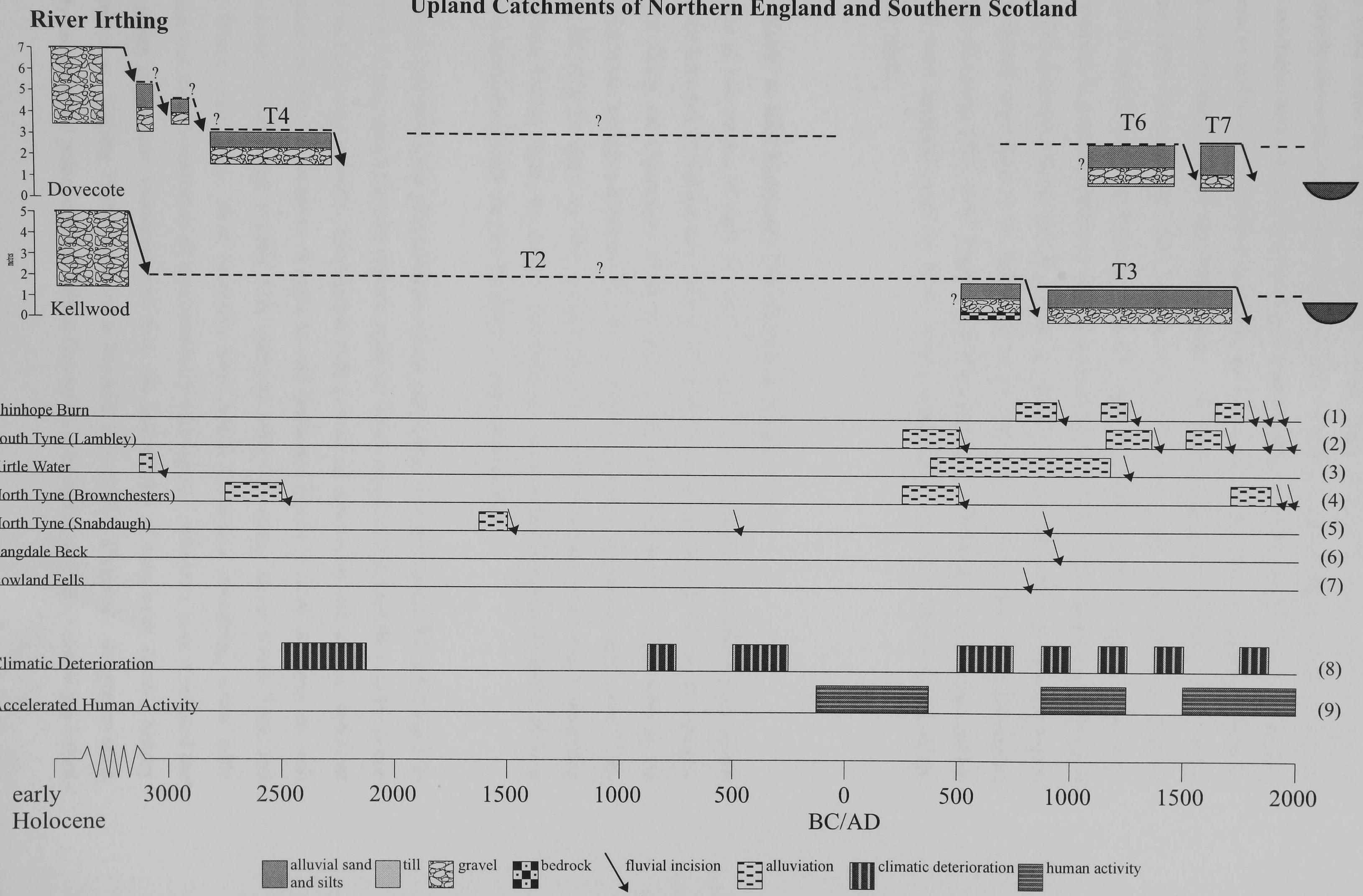
Key for sources of alluvial data provided below. Sources of data for periods of climatic deterioration and accelerated landscape disturbance are also listed below.

1. *Thinhope Burn.* **Macklin, M. G., B. T. Rumsby, et al.** (1992a).
2. *South Tyne (Lambley).* **Passmore, D. G. and M. Macklin** (1997; 2000).
3. *Kirtle Water.* **Tipping, R.** (1995).
4. *North Tyne (Brownchesters).* **Moores, A. J.** (1998).
5. *North Tyne (Snabdaugh).* **Moores, A. J., D. G. Passmore, et al.** (1999).
6. *Langdale Brook.* **Harvey, A. M.** (1985), **Harvey, A. M.** (1997).
7. *Bowland Fells.* **Harvey, A. M. and W. H. Renwick** (1987), **Harvey, A. M.** (1997).
8. *Periods of climatic deterioration.* **Barber, K. E. et at** (1994a; 1994b), **Haslam, C. J.** (1987), **Mauquoy, D. and K. Barber** (1999a; 1999b), **Rumsby, B. T. and M. G. Macklin** (1994), **Stoneman, R.** (1993), **Hughes, P., D. Mauquoy, et al.** (2000).
9. *Periods of increased human activity and accelerated landscape disturbance.* **Ferguson, R. S.** (1890), **Banks, F. R.** (1977), **Higham, N.** (1986), **Winchester, A. J. L.** (1987), **Barber, K. E., L. Dumayne, et al.** (1993), **Bewley, R. H.** (1994), **Dumayne, L. and K. E. Barber** (1994), **Dumayne, L.** (1995), **Manning, A., R. Birley, et al.** (1997).

The chronology for the periods of climatic deterioration and human activity are based on the radiocarbon age spans and documented evidence from the listed publications.

Chronology of Alluviation, Incision and Episodes of Climatic Deterioration and Human Activity in Upland Catchments of Northern England and Southern Scotland

Figure 7.1



7.1.1 The late Pleistocene - Holocene transition to the early Holocene

The high fluvial terrace (T1) at Dovecote lies between two and four metres above the lower valley floor while at Kellwood and Breconhill, high terraces lie three and five metres respectively above the lower fluvial terraces (Fig 5.6 and 6.4). Direct dating for these features is not available; however, the terrace morphologies and the vertical height difference between the terraces and lower valley floor are comparable to terraces elsewhere in upland catchments which are attributed to the late Pleistocene - Holocene transition (Macklin *et al.* 1992a, Tipping 1995, Howard *et al.* 1999, Moores *et al.* 1999). Such high terrace units are common in British upland river catchments, typically comprise coarse grained sediment and their abandonment is generally believed to have formed by early Holocene entrenchment (Macklin 1999). This incision reflects fluvial adjustment to isostatic rebound, reduced sediment supply and increased vegetation cover following valley deglaciation at the end of the Devensian (Macklin & Lewin 1986, 1997, Passmore & Macklin 2000). The timing of valley deglaciation in north west England (and the River Irthing catchment) was *circa* 18,000 to 14,500BP (Harvey 1997).

7.1.2 Early to mid Holocene (Mesolithic to Bronze Age)

Evidence of two metres of early to mid Holocene fluvial incision is provided by the height difference between fluvial terraces T2 and T3 at the Dovecote reach (Fig 5.1). In the absence of direct dating, the chronology of the terraces is determined by their position between the late Pleistocene terrace and terrace T4, the alluviation of which continued until *circa* 2240-1920cal.BC (Fig 5.6 and 7.1). The morphology of the valley floor thus indicates downcutting by the River Irthing during the early to mid Holocene with net incision into the valley floor at Dovecote continuing until the late Neolithic to early Bronze Age.

An early to mid Holocene palaeochannel reach associated with the terrace T2 (DC1 Fig 5.3) contained a fine grained fill with organic material which suggests that until the mid Holocene fluvial incision was episodic, interspersed with periods of alluviation and organic sediment accumulation. The preservation of early to mid Holocene fluvial terraces at Dovecote with palaeochannels containing organic fills contrasts with the nearby River South Tyne and Kirtle Water catchments. Here extensive later lateral floodplain reworking, water table lowering and the accumulation of predominantly minerogenic sediments have precluded the preservation of organic sediments and thus, the opportunity of long term alluvial history reconstruction (Tipping 1995, Passmore & Macklin 1997;2000). Therefore, the preservation of early terraces and palaeochannel fills at Dovecote, although fragmentary across the valley

floor, denotes limited Holocene lateral reworking of floodplain sediments. Similarly, early Holocene terraces have been described for the River Rede floodplain at Otterburn, Northumberland where limited lateral floodplain reworking has enabled the preservation of a long Holocene fluvial sequence (Moores 1998, Moores *et al.* 1999).

7.1.3 Mid to late-Holocene (Bronze Age to Romano-British period, 2500BC - 400AD)

Radiocarbon dates from basal palaeochannel fill sediments indicate that mid Holocene planform channel change and the commencement of palaeochannel infilling along the extended reach at Dovecote occurred *c.*2440-1920cal.BC (Fig 7.1). This period saw gravel aggradation in the Cheviots, Northumberland (Tipping 1992; 1998), fluvial incision along the River North Tyne at Brownchesters (Moores *et al.* 1999) and accelerated fluvial activity in the upper River Severn catchment, Wales (Taylor & Lewin 1997) and the River Feshie, in the Cairngorms (Robertson-Rintoul 1986). Significantly, proxy climate records from nearby ombrotrophic bogs show 2000BC as a period of wetter climatic conditions (Stoneman 1993, Barber *et al.* 1994a - Fig 7.1). Moreover, pollen records and archaeological data indicate that human activity in the River Irthing catchment during the late Neolithic and early Bronze Age was restricted to small scale woodland clearances (Dumayne 1995). There is little evidence, therefore, for widespread changes in catchment conditions and landscape disturbance and consequently the chronology of localised floodplain construction along the River Irthing suggests the sensitivity of the reach to climatic variability. Elsewhere, comparable alluviation and incision is thought to have been strongly influenced by Bronze Age activity (e.g. Taylor & Lewin 1997 for the River Severn). Tipping (1998) also considered localised aggradation along tributaries of the River Till to be correlated with human activity (including deforestation) alongside climatic forcings while subsequent reduction in alluviation corresponded with decreases in human activity. Therefore, although the data from Dovecote suggest climatic deterioration, and consequent changes to flood frequency and magnitude (Macklin & Lewin 1993; 1997) as a factor in the instigation of channel change, examples elsewhere prove the importance of localised landscape disturbance on channel instability. As the documented archaeological record from valley floors in the River Irthing catchment (and northern Cumbria as a whole) is poor (McCarthy 1995), prehistoric human impact on floodplain environments at the valley floor level at a local scale remains a possibility.

7.1.4 Anglo-Saxon to Medieval period (400AD-1400AD)

Dating of organic channel fill sediments of, potentially, one of the oldest Holocene palaeochannels at the Kellwood reach (KW2 - Fig 6.1), reveals that channel abandonment occurred shortly before 670-970cal.AD. No record of fluvial sediments at Kellwood dating between the early Holocene and the first millennium AD were obtained, hence the alluvial record extends only over the past 1300 years. However, the floodplain geomorphology of Kellwood reflects a series of extensive lateral channel avulsions which extend across the northern side of the Holocene valley floor (Section 6.1). Therefore, the age of the floodplain at Kellwood is complex as the palaeochannels may represent older channels re-entered by the River Irthing following avulsion (Kalicki *et al.* 1996). Moreover, if the palaeochannels at Kellwood represent reworked channels older than 670-970AD then the terrace sediments will also date back further than 1300 years. Furthermore, the alluviation of fluvial terraces may have been coeval, therefore, the terraces may not be chronologically distinct. In comparison, the late Holocene age of the valley floor at Langdon Brook, Lancashire has resulted from the combined tendency towards avulsion into older channels and the narrow floodplain width (Hitchcock 1977, Harvey 1985). The localised braided planform and high slope of Langdon Brook however contrasts with the meandering planform of the River Irthing, which is more comparable with lower gradient stable reaches in north west England (Harvey 1985).

The valley floor morphology at Kellwood can be compared with the River Rede, Northumberland (Moores 1998) where floodplain palaeochannels indicate laterally stable channels tending to episodic avulsion. Avulsion here is attributed to low channel gradients and valley morphology, alongside temporal differences in coarse sediment supplies and catchment land use histories (Passmore & Macklin 1997, Moores *et al.* 1999). This tendency contrasted with the fluvial incision, lateral reworking and alluviation evident in other upland catchments (e.g. Macklin *et al.* 1992a; 1992b, Tipping 1998, Passmore & Macklin 2000). The character of catchment conditions along the River Irthing could also relate to avulsion phases. Channel slope at the Kellwood site is approximately 0.00185, whereas that along the upstream Dovecote reach is 0.00219, thus indicating a drop in channel slope along the River Irthing from upstream of the Kingwater tributary to downstream. The lower channel gradient and subsequent reduction in stream power therefore may have contributed to a propensity towards avulsion (cf. Slingerford & Smith 1998), however, the characteristics of channel and floodplain substrata may also be of significance.

From exposed bank sections along the River Irthing floodplain, it is considered that the valley floor is lined with glacio-fluvial coarse sands and gravels (Table 5.2), into which the river has

incised. Cores taken from the palaeochannel KW2, at the deepest points, have cut through a thin layer of gravel to red sandstone bedrock beneath (Fig 6.15). Moreover, the active River Irthing channel bed, lying at an equivalent height to the channel bed of KW2 (Fig 6.5) is presently inset within bedrock, thus providing an indication of the former cover of gravels across the valley floor as well as representing the limit to net fluvial incision during the late Holocene. The significance of the bedrock substrate may possibly be linked to the frequent avulsions at Kellwood. Fluvial incision into upland valley floors in enabled by the competence of the rivers to transport the coarse glacial sediments that infill the valley floors (Macklin & Lewin 1986, Macklin 1999). Fluvial incision through the boundary between the coarse sands and gravels and the bedrock at Kellwood will have changed the physical parameters of the channel and thus impacted upon the nature of channel change and floodplain construction (Passmore & Macklin 2000). Elsewhere, this trend has been observed for the River Severn at Llandinam, where local incision down to bedrock signified a limit to lateral floodplain erosion due to changes in the characteristics of river bed and banks (Brewer & Lewin 1998). Localised changes in substrate along the River Irthing, therefore, have in part determined the patterns of floodplain development over, at least, the past 1300 years. However, due to the complex patterns of floodplain evolution at Kellwood, elucidating the full Holocene alluvial history prior to 670-970cal.AD necessitates more extensive floodplain sedimentological analysis and dating control than obtained for the present research.

The chronology of channel abandonment and palaeochannel infilling at Kellwood dating from *c.*670-970 cal.AD (Fig 7.1) is significant, as comparison with British upland alluvial histories reveals a broad coincidence with periods of accelerated fluvial activity (Fig 7.1). Macklin *et al.* (1992b), for example, found extensive fluvial incision at Thinhope Burn, in the upland reaches of the River South Tyne catchment, to have occurred between 600-890cal.AD. A period of major erosion and aggradation has also been recorded across the Borrowdale and Langdale valleys (Fig 7.1) around 1000BP (*circa* 1000AD) and on the River Dane floodplain at 1200BP, *circa* 800AD (Harvey 1997), all located to the south of the River Irthing catchment. To the north of the Irthing, alluvial records from Kirtle Water demonstrate accelerated alluviation between 800 and 1100AD (Tipping 1995a). The period between 700 and 1000AD corresponds with a shift to cooler and wetter climatic conditions (Barber *et al.* 1994a, Mauquoy & Barber 1999b - Fig 7.1) suggesting a link between accelerated fluvial activity in north west England and climatic deterioration. However, increases in fluvial activity across the River South Tyne catchment were thought to have been augmented by antecedent conditions created by deforestation during the Iron Age and Romano-British period (Macklin *et al.* 1992a, Passmore & Macklin 2000). Accordingly, within the River

Irthing catchment, anthropogenic activity and landscape degradation between *c*.200BC and 300AD have been linked to the expansion of late-Iron Age communities and subsequent Roman occupation, with the construction of Hadrian's Wall and numerous military settlements (Dumayne 1993, Dumayne & Barber 1994, McCarthy 1995, Manning *et al.* 1997). The route of Hadrian's Wall follows the northern valley side of the extended study reach. It is possible, therefore, that changes to catchment conditions exacerbated the response of the River Irthing at the Kellwood site to climatic deterioration, resulting in enhanced localised planform change.

Dating of basal palaeochannel fill sediments bracketed two fluvial terraces at the upstream part of the reach between 2440-1920BC and 1410-1620AD (Fig 7.1). The height of the terraces (T5 and T6, Fig 5.6) and the morphology of associated palaeochannels (DC5 and DC4, Fig 5.1) indicate a limit to the net incision experienced during the early to mid Holocene and a tendency, from the mid Holocene onward, to lateral channel migration and avulsion. Such late Holocene lateral channel change contrasts with the pronounced incision seen in upland catchment systems (Tipping 1995, Passmore & Macklin 1997; 2000) and has enabled the preservation of organic palaeochannel fill sediments (cf. Moores et al 1999).

7.1.5 Post Medieval period (1400-1700AD)

Determination of the chronology of terrace alluviation (of T6, Fig 7.1) prior to the abandonment of palaeochannel DC4 (Fig 5.1) at Dovecote is limited to a radiocarbon date from basal palaeochannel fill sediments. This places the timing of channel abandonment at prior to 1410-1620cal.AD. The terrace and palaeochannel geomorphology indicate channel abandonment occurred as a result of chute cut off or avulsion. The predominance of lateral channel change during the late Holocene along the upstream section of the study reach could link to intrinsic physical thresholds determined by the valley floor substrate. Evidence is provided by the palaeochannel fill sediments, that prior to channel abandonment the River Irthing had incised through the interface between glacio-fluvial gravels and cohesive clays (Section 5.1). These underlying clays are potentially glacio-lacustrine deposits (Van der Meer & Warren 1997) which present a more resistant substrate than coarse sands and gravel. At reach scale, such localised changes to valley floor substrate can impact upon the patterns of floodplain development (Brewer & Lewin 1998). For example, investigations along the River South Tyne observed that incision into resistant till or bedrock resulted in lateral instability (Passmore & Macklin 2000). Therefore, the interface between glacio-fluvial gravels and underlying till at Dovecote is an important factor in influencing the characteristics of

floodplain construction. However, it is acknowledged that changes in flood hydrology, catchment characteristics and the relative magnitudes of human activity are also highly significant (Tipping 1995, Moores *et al.* 1999, Passmore & Macklin 1997; 2000).

The chronology of post Medieval planform channel change coincides with extensive alluviation in the middle reaches of the River Tyne catchment (Macklin *et al.* 1992b) and fluvial incision in the upland River South Tyne tributaries (Passmore & Macklin 1997). Fluvial activity on the River Rede over the historic period concluded in a net aggradation of sediments on the floodplain surface (Moores *et al.* 1999). Proxy climate records for this period (Fig 7.1) indicate cooler and wetter conditions, linked to the onset of the Little Ice Age (Mauquoy & Barber 1999a; 1999b). Palynological records from nearby Bolton Fell Moss suggest that agricultural activity decreased during this period, reducing the trend of landscape disturbance during the previous 400 years i.e. the Medieval period (Barber *et al.* 1994a). Therefore, the timing of channel change may correspond with climatic deterioration and evidence of accelerated fluvial activity in upland river catchments. The response of the River Irthing contrasts with trends seen elsewhere, as there is no evidence of entrenchment or accelerated alluviation (Passmore & Macklin 1997; 2000). However, the planform channel change along the River Irthing may be a localised response to the catchment conditions and fluvial regime (Taylor & Lewin 1997).

7.1.6 The eighteenth and nineteenth centuries (1700-1900AD)

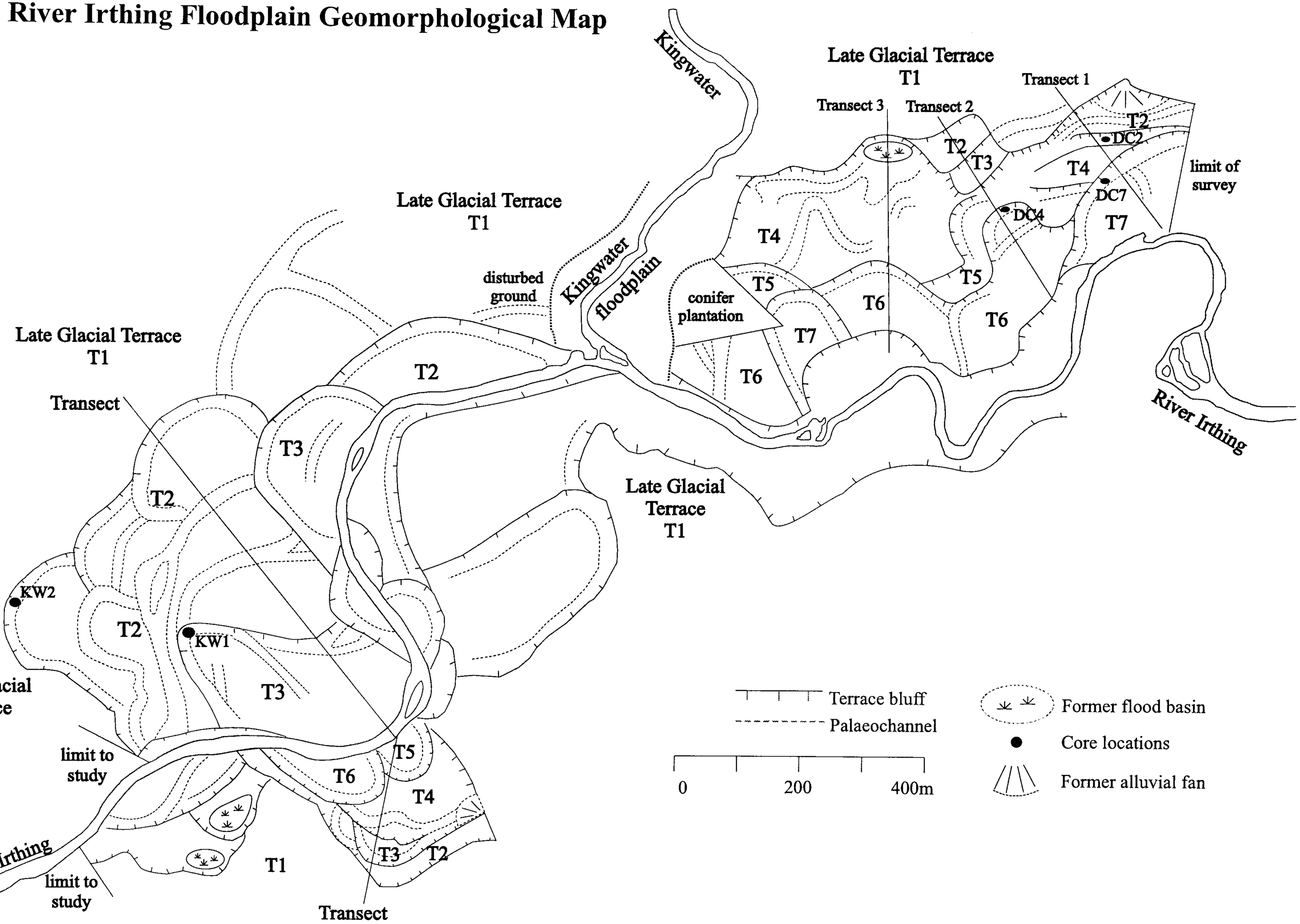
Differences in the course of the River Irthing as seen from historic maps surveyed in 1771-2 and 1821-2 show evidence for significant planform channel change (Fig 5.7 and 6.6). Downstream of the Kingwater tributary, there was also a widening of the active channel belt and the formation of mid channel and point bars. The historic maps' depiction of extensive planform change infers changes to the flood regime and sediment load (Harvey 1977; 1985). From documentary evidence it is known that in 1771, northern England experienced large flood events, the severe nature of which caused extensive damage to bridges and infrastructure in the River Tyne, River Tees and River Wear catchments (Archer 1992). High magnitude flooding was also recorded in the River Irthing catchment although damage to infrastructure was not documented (Mawson 1971). Investigations into flood frequency and magnitude undertaken in the neighbouring River Tyne catchment have revealed the late 18th century period as one of high magnitude flooding resulting in extensive fluvial erosion, incision and sedimentation (Rumsby 1991). Such changes to the fluvial regime and flood hydrology related to variations in atmospheric circulation patterns (Rumsby & Macklin

1994). Moreover, proxy climate records from ombrotrophic bogs in the upper River Irthing catchment reveal 1770-1800 AD as a period of increased effective precipitation associated with the final stages of the Little Ice Age (Mauquoy & Barber 1999b). Therefore, observations of recent historic channel change suggest a link between channel change along the River Irthing and climatic variability. Moreover, the synchronous response between the upstream and downstream River Irthing sites and catchments elsewhere in northern England indicate a possible regional scale effect of climatic deterioration on flood hydrology. Variability exists, however, in the response of the fluvial regime to environmental change. Within the River South Tyne and River Tyne catchments, for example, increases in flood frequency and magnitude during the late 18th century instigated high rates of fluvial incision, locally into valley floor bedrock (Macklin *et al.* 1992a, Rumsby & Macklin 1994). Conversely, along River Irthing reach the period was characterised by meander cut-offs and channel avulsion. This pattern of late 18th to early 19th century planform change suggests a localised response to the flood regime.

Later historical channel planform change, as recorded on historic maps surveyed in 1821-2 and the 1840s, comprised reductions in active channel width due to channel rationalisation and the infilling of abandoned side arms. The localised development of mid channel and point bars also occurred. These changes in channel pattern indicate a period of local sediment transfer and aggradation and, therefore, represent a distinct change in the characteristics of floodplain evolution from the late 18th century (cf. Passmore *et al.* 1993). The early to mid 19th century saw extensive flooding in the River Wear catchment and in the river catchments in Northumberland (e.g. River Till and River Coquet) which resulted in bridge damage (Archer 1992). Conversely, planform channel changes along the River Irthing, appear to more closely correlate with the River Tyne catchment where the mid 19th century was characterised by moderate floods, lateral erosion and sediment transfer (Rumsby & Macklin 1994).

Figure 7.2

River Irthing Floodplain Geomorphological Map



Summary

Periods of planform change, alluviation and incision along the full extended study reach of the River Irthing date to 2440-1920cal.BC, 670-970cal.AD, 1410-1620cal.AD and 1771-1822AD (Fig 7.1). When compared with proxy climate records taken from Bolton Fell Moss, Walton Moss, Felecia Moss and Coom Rigg Moss (situated within or proximal to the River Irthing catchment-Stoneman 1993, Barber *et al.* 1994a; 1994b, Mauquoy & Barber 1999a; 1999b) each period corresponds with climatic deterioration. Due to the continuum between human impact and climatic events, Brown (1997a) warns against overemphasising the relative magnitude of climatic forcings on accelerated fluvial activity. The chronology of floodplain evolution does, however, suggest a link between localised channel change and climatic deterioration. However, it should be borne in mind that anthropogenically created antecedent conditions, as may have occurred prior to 670-970cal.AD from late-Iron Age and Romano-British activity, will have impacted upon the magnitude and characteristics of fluvial response. Furthermore, the periods of incision and alluviation along the study reach may be a localised response to the flood regime and sediment supply or small changes to catchment land use.

Differences are evident between the variable chronology and character of valley floor evolution of the upstream and downstream segments of the extended study reach (Fig 7.1). Variation between the sites is also suggested by the planform sinuosity of both palaeochannels and the active river channel, which show a wider channel and lower sinuosity downstream of the Kingwater tributary (Fig 7.2). The input of the Kingwater may account for a proportion of upstream-downstream variability, through the contribution to the catchment of the Kellwood site and consequent affects on sediment load and flood regime. Differences in land-use practices between the Kellwood and Dovecote catchments may also be of significance (Taylor & Lewin 1997). Moreover, the geomorphology of the extended reach reveals a variable valley floor configuration (Macklin 1999), resulting from Pleistocene till deposits (Fig 3.2, Plate 3.2). The southern side of the Holocene valley floor at Dovecote is consequently more confined than downstream (Fig 7.2), effecting localised variability in sediment accommodation, supply and transport (Lewin 1992, Passmore & Macklin 1997; 2000). Despite the differences between the two sites, the late Holocene has seen similarities in floodplain evolution as the River Irthing has been prone to laterally extensive planform change. Trends of late Holocene floodplain construction have been partly linked to incision through the interface between glacio-fluvial gravels and underlying cohesive bedrock and clays at both sites.

7.2 Palaeochannel Development along the River Irthing Floodplain

Vegetation community development of the five palaeochannel reaches selected for detailed investigations (DC2, DC4, DC7, KW1 and KW2) has been modelled (Figs 7.3 to 7.7) based on the palaeochannel morphology, sedimentary facies and plant macrofossil data described in Chapters 5 and 6. Palaeochannel habitat development has been analysed with respect to the characteristics of palaeochannel infilling and organic matter accumulation, disturbance (through flooding and human activity) and vegetation succession. The affects and influence of reach scale valley floor evolution and proxy records of environmental change are also discussed. The models are compared with contemporary and palaeoecological records of floodplain habitat development. Each model is described and discussed below.

7.2.1 Temporal habitat development for palaeochannel DC2

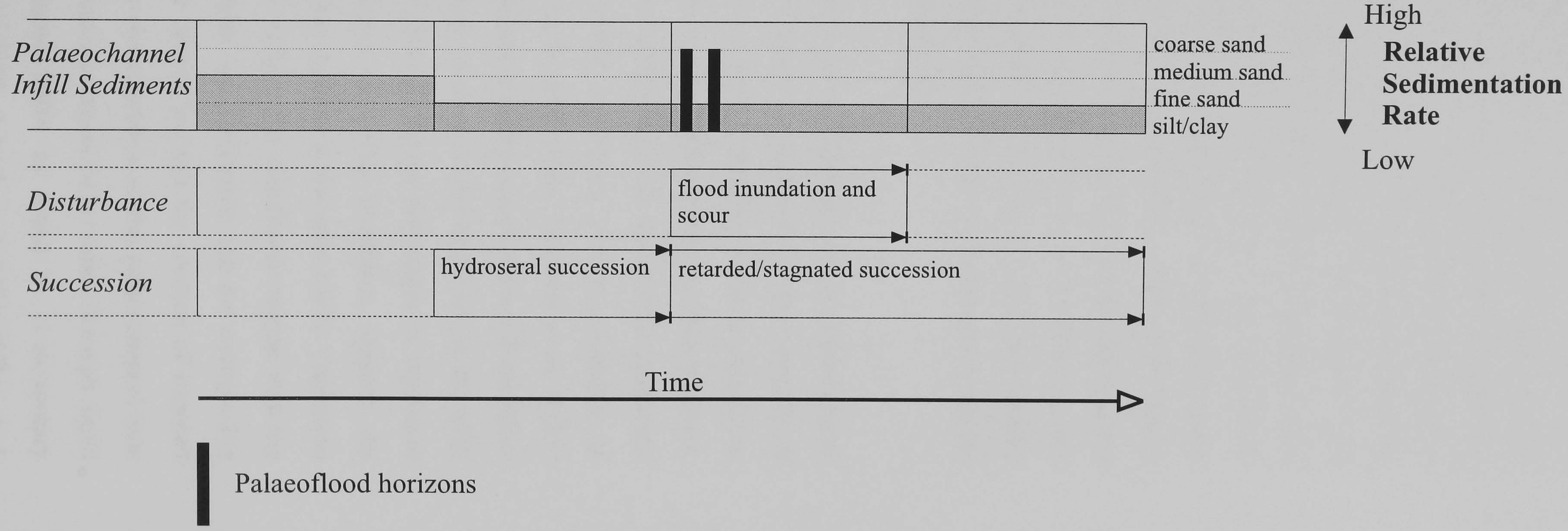
The model of habitat development for palaeochannel DC2 is illustrated in Figure 7.3. The earliest processes of palaeochannel development are characterised by the infilling of morphological depressions in the channel bed with coarse sediment (Fig 5.11, abandonment facies Sp) which suggests a continued flow through the channel. The earliest stage of development reflects the period of channel abandonment or rationalisation which occurred *circa* 2440-1920cal.BC (T4, Table 5.1). The form of channel abandonment is thought to be localised avulsion or the rationalisation of a wide active channel belt (Section 5.1) which has enabled continued high energy inputs through the palaeochannel. Significantly, such environmental conditions restrict evaluation of palaeochannel vegetation due to the potential dominance of *ex situ* macrofossils in the stratigraphy (Warner & Barnet 1986). It is possible, however, that only a thin vegetation cover existed within the palaeochannel habitat during the earliest stages of development (Fig 7.3) due to a continued connection with the main channel and the high sedimentation rates (Amoros & Bornette 1999).

Following the deposition of abandonment sediments, a reduction in sedimentation rates and a progressive decoupling between palaeochannel and active channel is indicated by the fining of sediment facies up profile (Fig 5.12). This enabled the establishment of aquatic and wetland communities (Fig 7.3, plant macrofossil zone 2, Fig 5.14). The input of fine grained sediments through overbank deposits (facies Sh and Fsc, Fig 5.11) and associated nutrient inputs following abandonment, combined with a reduction in sedimentation rate, changed environmental conditions by way of terrestrialisation and trophic change and provided

Figure 7.3

Model of the Temporal Development of DC2

Palaeochannel Habitat	former river side arm, limited vegetation cover	aquatic and wetland vegetation communities, vegetation zonation	wetland vegetation	thin cover of wetland vegetation and grasses
Associated Macrofossil Zone & Species	1 *Juncus spp, Nitella, Daphnia*	2 *Alisma plantago-aquatica, Potamogeton spp, Nitella*	3 *Juncus spp, Callitriche spp Alisma plantago-aquatica*	4 *Juncus spp, Glyceria fluitans*



suitable regeneration niches for vegetation colonisation (Van der Valk 1981). Zonation of vegetation within the palaeochannel is assumed from the spatial variation in organic matter within the sediments as illustrated by the variable distribution of facies C and Fsc within the sediment fill (Fig 5.11), with patches of sediment with higher organic contents. This may be linked to the development of an alluvial plug at the upstream end of the palaeochannel reach, whereby coarse sediments are deposited at the junction between the active channel and palaeochannel. The resulting vegetation cover (and organic matter - Fig 5.11) decreases with distance from the protective alluvial plug with less organic rich sediment in the downstream transects (Fig 5.11). This creates a vegetation gradient, or different zones of vegetation, along the palaeochannel which is linked to the magnitude of fluvial influence (Bornette & Amoros 1991). Zonation and wetland establishment, therefore, are enabled by the decoupling between active channel and palaeochannel which, although not disclosed by the infill sediments, may be linked to the development of an alluvial plug (Erskine *et al.* 1992). Zonation also implies spatially organised hydroseral succession, potentially linked to the environmental gradients created by fluvial inputs (Bornette *et al.* 1994c, Hughes 1997).

Subsequent to the establishment of pioneer aquatic and wetland species in palaeochannel DC2 (Fig 7.3) high magnitude flood inundation occurs as indicated by the presence of palaeoflood horizons (Fig 5.13). The period of large flood events and resultant inundation corresponds with evidence for an attenuation of the aquatic habitat (plant macrofossil zone 3, Fig 5.14). The reduction in aquatics implies an exacerbation of terrestrialisation processes, through episodic increased sedimentation rates during inundation and the possibility of habitat destruction by flood scour (cf. Amoros & Bornette 1996). Hawkins *et al.* (1997) found that effects of flooding could result in vegetation destruction and removal if the initial vegetation cover was sparse. Although the magnitude of scour cannot be proven by the infill sediments, the presence of only patchy vegetation cover during the first stages of vegetation development and the reduction in aquatic species following inundation suggests the destruction of vegetation by high magnitude flooding (Amoros & Bornette 1999). Vegetation community composition subsequent to inundation reflects the disturbance regime with the preponderance of species (*Juncus* spp, Charophytes and *Callitriche* spp for example-Fig 5.14) which respond quickly to flooding, habitat destruction and the creation of exposed surfaces (Abernethy & Willby 1999). The biotic characteristics of the palaeochannel thus represent the affects of fluvial dynamics and species regenerative traits, through rapid response adaptations (Barrat-Segretain & Bornette 2000) as found in contemporary floodplain systems (e.g. Bornette *et al.* 1994c, Fastie 1995, Robach *et al.* 1997, Willby *et al.* 2000). Therefore, habitat development signifies the magnitude of influence of the

contemporary channel on palaeochannel development (Bornette *et al.* 1994a). Terrace alluviation (of T4, Fig 5.3) and subsequent abandonment of palaeochannel DC2 signified the limit to net fluvial incision along the extended study reach (Section 7.1.2). Therefore, the re-occupation of the palaeochannel during high stages may link to the transition in valley floor development from entrenchment to predominantly lateral planform change and reduced incision. A tendency to lateral channel change enabled the inundation of lower fluvial terraces and palaeochannels during peak flows.

Wetland community development in the palaeochannel subsequent to high magnitude flooding does not follow a similar successional trend to some contemporary systems (e.g. Bornette & Amoros 1991), as only small change in community composition occurs comprising wetland and wet grasses (macrofossil zone 3 and 4, Section 5.2.3). The sedimentary record indicates continued overbank deposition of silts and clays and limited organic matter accumulation that may encourage persistent aquatic and wetland communities and restricted hydroseral succession (Amoros *et al.* 1987). The results correspond with data from the River Rhône palaeochannels where frequently flooded communities experienced fluctuations in species abundance but little change in community composition (Bornette *et al.* 1994d). The research spanned a *circa* eight year temporal scale which the researchers questioned in the light of the absence of vegetation community change; however, the sedimentary and macrofossil record of DC2 show that equivalent effects of flooding may persist over a longer temporal scale.

Information regarding further development of the palaeochannel habitat is limited due to the degradation of the macrofossil record by aerobic conditions and the oxidisation of organic matter. The upper limits of the macrofossil record represent the difficulties of reconstructing temporal ecological change from palaeochannel fills, as the lowering of and fluctuations to the water table following valley floor evolution are typical of upland river systems (Tipping 1995, Passmore & Macklin 1997; 2000). Since the abandonment of palaeochannel DC2, low rates of channel incision and a tendency towards lateral channel change has enabled the preservation of organic material in the lower part of the palaeochannel fill.

The development of palaeochannel DC2 indicates the significance of fluvial inputs upon palaeochannel habitats. This contrasts with trends of contemporary upland fluvial systems where channel rationalisation and entrenchment, following river regulation, has lead to a reduction in aquatic and wetland communities and the dominance of mature woodlands with low biodiversity (Marston *et al.* 1995, Bravard *et al.* 1997, Mendonca-Santosa *et al.* 1997).

The predominance of low energy fine sediment infilling reflects the absence of high rates of vertical channel incision which would isolate the palaeochannel from the active channel (Bravard *et al.* 1986; 1997). However, the initial decoupling between active channel and palaeochannel indicate the presence of an alluvial plug of the lateral migration of the channel, which reduced sedimentation rates and enabled vegetation establishment (Fig 7.3). Therefore, palaeochannel development in DC2 reflects an intermediate form of habitat development, between extensive fluvial inputs (and an absence of vegetation establishment) and palaeochannel isolation which would lead to autogenic vegetation succession (Bornette *et al.* 1994a). The channel was abandoned during a period of low magnitude, small scale human activity in the River Irthing catchment (Dumayne 1995). Moreover, the persistence of overbank sedimentation indicates an absence of river regulation or flood alleviation during the period of palaeochannel infilling (cf. Bravard *et al.* 1997). Therefore, the model of palaeochannel development illustrates a natural system response to fluvial dynamics at the reach scale.

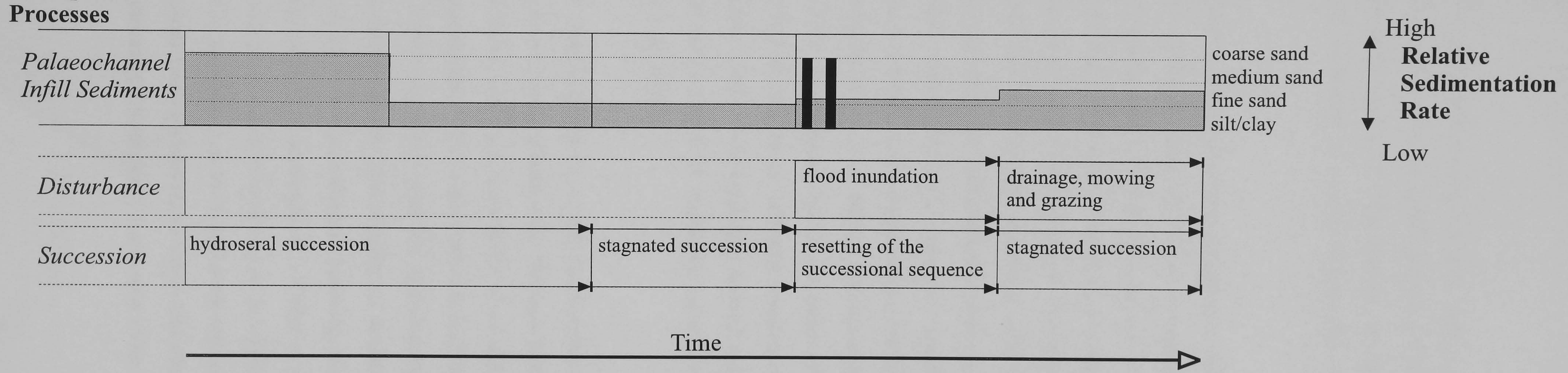
7.2.2 Temporal habitat development for palaeochannel DC4

The model of palaeochannel habitat development for DC4 is illustrated in Fig 7.4. Following channel abandonment and the creation of palaeochannel DC4, the fill sediments reflect the rapid deposition of coarse sands. The upstream sediment fill reflects an alluvial plug (facies Sp-p, Fig 5.18) rapidly deposited from channel bedload sediments and resulting from the acute angle between abandoned and active channel (Brown 1997a). Amoros & Wade's (1996) classification of meander cut-offs comprises the deposition of an alluvial plug, which results in the creation of an oxbow lake and rapid vegetation establishment. This classification in consistent with the post-abandonment development of palaeochannel DC4 where the rapid establishment of submerged macrophytes (e.g. *Potamogeton* spp.) occurred in the lee of the plug, protected from upstream fluvial inputs (transect 2, Fig 5.17). Pokorny *et al.* (2000) found the diversity of a reconstructed oxbow community to be high, partly attributed to the absence of shade and consequent species competition. Conversely, the number of species in the first stages of palaeochannel development in DC4 is low (Fig 5.20). This may be attributed to low velocity, continual backwater inputs (Facies Fl, Fig 5.18) and subsequent turbidity (cf. Rodwell 1995, Amoros & Bornette 1999). However, the macrofossil record may also reflect taphonomic processes whereby only the more durable seeds survived.

Figure 7.4

Model of the Temporal Development of DC4

Palaeochannel Habitat	oligotrophic - mesotrophic, slow flowing side arm/oxbow lake	oxbow lake/ waterlogged habitat aquatic and wetland vegetation	wetland and grassland vegetation	ruderal and aquatic vegetation	wetland and grassland vegetation
Associated Macrofossil Zone & Species	**1** *Potamogeton spp, Alisma plantago-aquatica*	**2** *Carex spp, Daphnia, Epilobium palustre, Salix*	**3** *Carex spp, Cicuta virosa,* Bryophytes	**4** Poaceae, *Daphnia, Salix Cerastium fontanum,*	**5** *Filipendula ulmaria, Alnus glutinosa, Rumex spp*



Therefore, although the aquatic community was established in the low energy conditions provided by the alluvial plug, aquatic vegetation and, potentially, the macrofossil record were also affected by fluvial inputs. From radiocarbon dating of basal organic sediments, it is known that the deposition of the alluvial plug occurred prior to 1410-1620cal.AD (T6 - Table 5.1).

Post-abandonment palaeochannel development was followed by a progressive reduction in fluvial inputs (Table 5.4) with a persistent (although reduced) aquatic component to the habitat and wetland, sedge swamp type vegetation establishment (macrofossil zone 2, Fig 5.20). The progression from aquatic to wetland communities has been enabled *via* fine sediment deposition suitable for wetland species establishment (Hupp & Osterkamp 1985), and *via* eutrophication of the palaeochannel by the nutrients associated with backwater sediments and the increase in biomass following vegetation colonisation (Amoros *et al.* 1987, Hughes 1997, Thoms 1999). Contemporary studies have also observed palaeochannel vegetation succession following fine sediment infilling and eutrophication, enabled by the presence of a protective upstream alluvial plug (Bornette *et al.* 1994a). Moreover, backwater inputs are also linked to the 'blocking' of the downstream end of the palaeochannel by alluvial plug development which is promoted by increased sediment trapping following vegetation establishment (Bornette & Amoros 1991). A downstream alluvial plug further reduces the fluvial inputs that effected the initial stages of vegetation establishment and encourages hydroseral succession (Bornette *et al.* 1998b).

Pokorny *et al.* (2000) found that the oxbow stage (equivalent to macrofossil zones 1 up to 2 in palaeochannel DC4) of a floodplain mire development persisted for 750 years before sedge swamp developed. Based on the sediment facies and plant macrofossil data, alluvial plug deposition and oxbow lake formation in palaeochannel DC4 constitutes 25cm of the 215cm of palaeochannel fill sediments (Fl facies, Table 5.4) which span 500 approximately years. Therefore, the life-span of the oxbow is relatively short. This rapidity of development is attributed to terrestrialisation, reduced fluvial inputs and a consequent lowering of the water depth (a significant variable in determining vegetation development - Cellot *et al.* 1994) alongside biomass and nutrient accumulation, resulting in eutrophication (cf. Rostan *et al.* 1987). The speed of vegetation change in DC4, therefore, can be linked to the type of channel abandonment which allowed rapid modifications (through backwater inputs and alluvial plug deposition) to the habitat conditions and encouraged hydroseral succession (Van der Valk 1981).

Habitat development following wetland development comprised a period of stagnated vegetation succession (Fig 7.4, macrofossil zone 3, Fig 5.20) as the habitat composition does not progress beyond a wetland community (cf. Amoros & Wade 1996, Bornette & Amoros 1996). The stratigraphic context reveals a reduction in organic matter while the reduction in aquatic species in the palaeochannel is related to terrestrialisation. Increases in bryophytes in a floodplain mire, as exhibited in DC4 (Fig 5.20, macrofossil zone 3) have been interpreted by Pokorny *et al.* (2000) as the result of increased oligotrophic groundwater inputs. Furthermore, increases in the proportion of low nutrient groundwater inputs from the hillslope aquifer can affect vegetation compositions, without increases in fluvial inputs (Bornette *et al.* 1996; 1998b). Therefore, the vegetation dynamics in the palaeochannel could be linked to hydrological changes. Considering the stratigraphic location of evidence for stagnated succession (zone 3, Section 5.3.3), it is likely to have occurred during the first 200-300 years following abandonment, as the palaeochannel began infilling during 1410-1620cal AD *circa* 500 years ago. Proxy climate records from ombrotrophic bogs in the River Irthing catchment have indicated that a period of major bog wetness began *circa* 1650AD, peaking between 1750AD and 1800AD (Fig 7.1) and is linked to the commencement of the Little Ice Age (Barber *et al.* 1994a, Mauquoy & Barber 1999b). As the macrofossil record reflects changes in environmental conditions but little direct influence from the main channel, the timing of stagnated succession in DC4 may possibly correspond with climatic deterioration and consequent changes in effective precipitation. Evidence from the present research does not consider human activity highly influential in determining palaeochannel vegetation community change, as the macrofossil data records no significant increases in ruderal species or species indicative of fertile ground (cf. Baker *et al.* 1993).

Following the period of stagnated vegetation succession (Fig 7.4), high magnitude flood inundation formed coarse sediment horizons in the palaeochannel fill (Fig 5.19). Although flood sediments are not evident within the macrofossil core (Table 5.4) the stratigraphic location of biotic change within the core (plant macrofossil zone 4 -Fig 7.4) lies within the sediment facies containing palaeoflood horizons. Resulting changes in the biotic characteristics of the palaeochannel include the input of ruderals and grassland seeds (macrofossil zone 4, Fig 5.20), commonly found in flood deposits (Abernethy & Willby 1999). A return of aquatic species, resulting from increased waterlogging of the channel or ponding in areas of flood scour and, consequently, a resetting of the hydroseral successional sequence were also evident (Bornette & Amoros 1991b, Bornette *et al.* 1994a). This resulted in the establishment of a habitat similar to that prior to inundation (Fig 7.4). Further dating would be necessary to fully correlate palaeoflood horizons with documentary evidence for

flooding (e.g. Mawson 1971, Rumsby 1991, Archer 1992), therefore assessment of the chronology of flooding is restricted.

The effects of flooding on palaeochannel development gives rise to three important and related issues. Firstly, the establishment of aquatic species implies the rapid response of species to the creation of regeneration niches by floods (cf. Barrat-Segretain & Bornette 2000) and consequently the importance of species regenerative traits in predicting the response of communities to disturbance (Henry *et al.* 1996). Secondly, the impact of flooding reflect the importance of applying a physical context to the interpretation of vegetation development (Fastie 1995), with the physical dynamics of the fluvial system often paramount in facilitating biotic trends (Bornette *et al.* 1998b). Lastly, the palaeoflood horizons were spatially limited to the downstream section of the palaeochannel reach (transects 3, 4 and 5) and were found during extensive sedimentological analyses, thus emphasising the importance of the high resolution reconstruction of palaeochannel fill sediments.

The most recent stage of palaeochannel development (Fig 7.4) reflects the establishment or return of wetland vegetation (macrofossil zone 5, Fig 5.20). However, there is little evidence for subsequent hydroseral succession, as the community remains as a wet meadow type habitat up to the present day (Fig 5.20). As the previous floods reset the vegetation successional sequence to an aquatic-wetland transitional habitat, the subsequent initiation of sedge swamp, the natural successor to the pioneer aquatics (Amoros & Wade 1996) indicates autogenic hydroseral succession. This, however, is short lived, potentially due to livestock grazing and mowing. In a natural successional sequence in floodplain mires, alder carr would follow a sedge swamp community (Cluzeau 1992, Pokorny *et al.* 2000). Conversely, the low vegetation cover and presence of eutrophic species in DC4 highlights the impact of anthropogenic activity (Baker *et al.* 1993, Case & Kauffman 1997).

In summary, the initial trends of palaeochannel habitat development, incorporating the rapid biotic response to changes in environmental conditions, were determined by the character of channel abandonment, sediment deposition and fluvial inputs, as observed in contemporary studies of meander cut-offs (Amoros & Wade 1996, Bornette *et al.* 1998b). Models predict autogenic habitat development (organic matter increases, eutrophication and hydroseral succession) in meander cut-offs following abandonment (Amoros *et al.* 1987, Amoros & Wade 1996). In contrast, the stagnated succession, flood disturbance and the resetting of hydroseral succession in palaeochannel DC4 suggest that palaeochannel habitat development

is a function of the contemporary landscape context as opposed to the former fluvial regime and channel abandonment type (Bridge 1993, Fastie 1995).

7.2.3 Temporal habitat development for palaeochannel DC7

Figure 7.5 illustrates the model of temporal habitat development for palaeochannel DC7. Channel abandonment occurred between 1771 and 1822AD through localised channel avulsion (Section 5.1, Fig 5.7). Following abandonment, the historic maps demonstrate that the upstream section of the palaeochannel rapidly infilled (Fig 5.7B), partly due to the acute angle of abandonment (Amoros & Wade 1996, Brown 1997a). This upstream plugging resulted in the dominance of backwater medium and fine sand backwater infill sediments (facies Fl - Fig 5.23). The plant macrofossil record for the early stages of infilling reflect limited vegetation development (macrofossil zone 1, Fig 5.25). This may result from rapid sedimentation (Amoros & Bornette 1999), but may also reflect a high energy environment which is not conducive to the preservation of plant macrofossils (West *et al.* 1993).

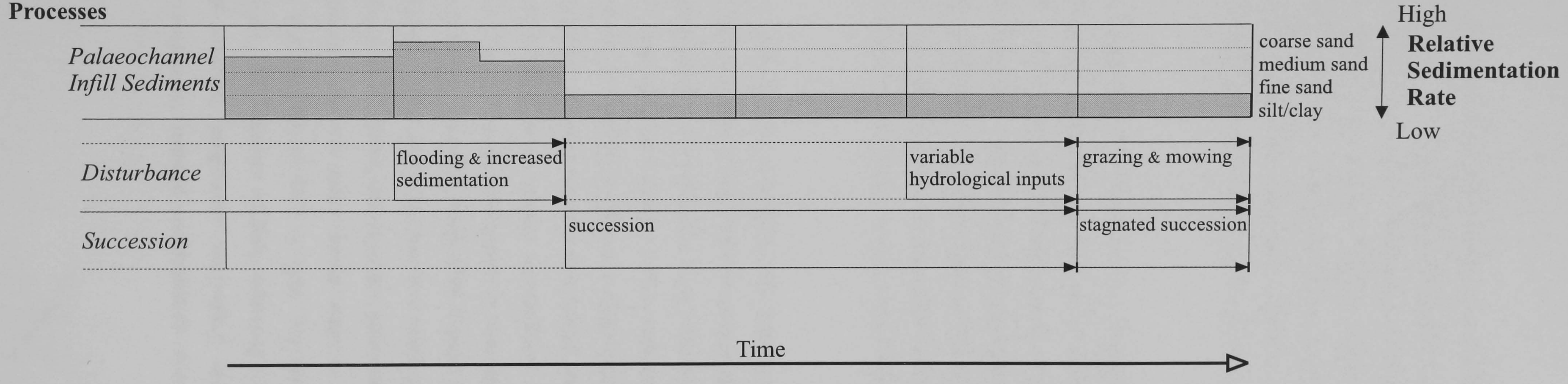
The sediment facies overlying the backwater Fl facies indicate higher sedimentation rates subsequent to backwater infilling (facies Sh, Fig 5.23 and 5.24) and suggest an augmented sediment supply or increases in flood magnitude. This period of infilling occurred prior to the 1840s when a wetland community is known to have existed within the palaeochannel (Fig 5.7D). Therefore, the higher sedimentation rates (of facies Sh), may result from the increased flood frequency and magnitude of the late eighteenth and nineteenth centuries and the subsequent period of localised sediment transfer exhibited on historic maps (Section 7.1.6). Such further increases in sedimentation rates (Fig 5.24) limits the extent to which palaeochannel vegetation could be evaluated due to the possibility of a high percentage of *ex situ* macrofossils in the stratigraphy (Collinson 1983). By the 1840s (Fig 5.7D) the creation of a bar at the downstream mouth of the palaeochannel initiated the decoupling between active channel and palaeochannel, reduction in sedimentation rates and an increase in *in situ* organic matter accumulation (LOI, Fig 5.25).

Although few macrofossil species were present in the lower basal sediments (facies Fl -Table 5.5) some aquatic vegetation was evident within the macrofossil record. A number of species, including *Potamogeton* spp and *Myriophyllum alterniflorum* persist through to the period of

Figure 7.5

Model of the Temporal Development of DC7

Palaeochannel Habitat	sparse vegetation, downstream connection with river	open aquatic oxbow habitat	oligotrophic - mesotrophic aquatic community	species poor sedge swamp	Alder carr with sub-communities	wet meadow and grassland
Associated Macrofossil Zone & Species	**1** *Chara*, Byrophytes	**2** *Potamogeton spp Myriophyllum alterniflorum*	**3** *Alisma plantago-aquatica, Daphnia, Potemogetan spp*	**4** *Carex spp, Mentha aquatica*	**5** *Alnus glutinosa, Solanum dulcamara, Callitriche spp*	**6** *Juncus spp,* Poaceae *Glyceria fluitans*



active channel and palaeochannel decoupling and associated reductions in sedimentation rates. Their presence signifies the establishment of a *Potamogeton-Myriophyllum* type community (Rodwell 1995). The persistence of species through lotic to lentic conditions (macrofossil zone 1 to 2, Fig 5.25) suggests that either they established during and tolerated the early fluvial regime in the palaeochannel or were present as seeds which only established through rapid response to ambient environmental conditions (Abernethy & Willby 1999). The habitat niche preferences of the species found suggest the latter case to be more probable (Rodwell 1995).

Following the initial stages of decoupling and vegetation establishment, the colonisation of an aquatic species (*Alisma plantago-aquatica*) which required high nutrient levels and the reduction of oligotrophic-mesotrophic species (e.g. *Myriophyllum alterniflorum*) was evident (macrofossil zone 3, Fig 5.25). This inferred increase in nutrient levels (eutrophication) as indicated by the vegetation community change and the increases to the organic content of the sediments (LOI, Fig 5.25), signifies firstly the commencement of autogenic succession (Amoros & Wade 1996) and secondly, the affects of a reduction in sedimentation rates and fluvial inputs (Bornette & Heiler 1994).

Continuing up the sediment profile, the aquatic species in the macrofossil record are replaced by a species poor wetland community dominated by sedge (*Carex* spp-macrofossil zone 4, Fig 5.25) reflecting the progression of autogenic hydroseral succession (Fig 7.5), with the replacement of an oligotrophic-mesotrophic open water community with a mesotrophic-eutrophic sedge swamp (Rodwell 1995). Therefore, the infilling of the palaeochannel resulted in a significant reduction in the aquatic component of the palaeochannel habitat through terrestrialisation. The change in habitat environmental characteristics is significant. If the development of a sedge swamp correlates with floodplain mire development in contemporary wetland systems (Lambert 1951, Bornette *et al.* 1994d, Amoros & Wade 1996, Odland 1997), while palaeoecological studies have reconstructed sedge swamp communities which persist for over 300 years (Singer *et al.* 1996, Pokorny *et al.* 2000), the complete palaeochannel sequence in DC7 (spanning 200 years) indicates that the sedge swamp stage is rapid. Therefore, autogenic vegetation succession in palaeochannel DC7 is rapid. The speed of vegetation succession is linked to the high rates of sediment infilling following channel abandonment (facies Fl and Sh) which enabled progressive decoupling between palaeochannel and active channel and consequently, reduced sedimentation rates and standing water levels (Bravard *et al.* 1997).

The vegetation composition of the palaeochannel following sedge swamp development comprises species representing an alder carr community (Rodwell 1991) and increases in diversity. This signifies a successional step from sedge swamp to floodplain woodland. The unhindered successional sequence highlights a continuation of autogenic change within the channel and an absence of high magnitude flood disturbance (Bravard *et al.* 1986). Furthermore, palaeoecological studies of floodplain mires have found alder carr to be the final vegetation successional stage (e.g. Wheeler 1992, De Klerk *et al.* 1997, Pokorny *et al.* 2000). According to Cluzeau (1992), *Alnus glutinosa* can take only 15 years to colonise 100-150m of eutrophic swamp as its seeds have effective dispersal mechanisms. Such a rapid rate of colonisation is evident in DC7. The colonisation of alder in former river channels may also be accentuated by its persistent presence on the peripheries of riparian sites, which allow it to quickly extend into floodplain mire habitats formed following channel abandonment.

The alder carr community in palaeochannel DC7 comprised an under-storey sub-community which included *Rumex sanguineus, Filipendula ulmaria, Carex* spp. and *Solanum dulcamara* (macrofossil zone 5, Fig 5.25). The species niche data for the sub-community reveal a variability in nutrient requirements, with species from mesotrophic and eutrophic habitats (e.g. *M. aquatica, F. ulmaria* and *S. dulcamara* - Grime *et al.* 1990). The presence and persistence of these species may infer a variability in hydrological inputs (cf. Bornette *et al.* 1994a, Wassen & Joosten 1996, de Mars *et al.* 1997), potentially from groundwater or overbank sources, although the sedimentary data reflects slow accumulating peaty sediments and no evidence for high magnitude flood inundation. The diversity of species present may be the result of groundwater inputs, as cut-off channels with high groundwater inputs can be dominated by early successional vegetation communities, requiring lower nutrient status habitats Bornette *et al.* (1994a). Pokorny *et al.* (2000) discuss the effect of peat mineralisation, which occurs when parts of the peat surface beneath alder carr are slightly elevated, dry out and sustain aerobic conditions which can result in a change to the trophic and hydrological status of the mire. Therefore the data may indicate either a change in groundwater inputs or the drying of patches across the palaeochannel, resulting in a mix of species with different environmental niches, while the process of vegetation succession and eutrophic mire status of the palaeochannel are maintained. In contrast to the trends described by Bornette *et al.* (1994a), the change in hydrological status of DC7 was not of sufficient magnitude to rejuvenate the successional sequence, although the change enabled the creation of environmental niches suitable for species requiring different trophic conditions to those of an alder carr. This, consequently, increased the biodiversity of the habitat.

During the most recent stage of development the alder carr and fen species are replaced by grasses and wetland species (macrofossil zone 6) within palaeochannel DC7 which signifies the upper limit to autogenic hydroseral succession and is representative of the present palaeochannel community composition. There is an absence of change in the character of infill sediments or indication of hydrological change. However, the low, dense, vegetation cover and composition suggests anthropogenic activity, including livestock grazing and mowing, as a cause of biotic change and termination of the successional sequence. Pokorny *et al.* (2000) speculate that alder carr communities persist for 100-150 years before die back occurs. Their palaeoecological study of an alder carr community found that the dying back of stands enabled the development of an open mire, which is sequentially re-colonised by alder after a period of time. This process occurs in mosaics within an alder carr which the researchers found difficult to extract from the macrofossil record. The termination of stands of alder due to old age may have occurred within DC7 as the decline is gradual and the species persist to the top of the fossil record. Therefore, the end of the alder carr community could have been the result of natural die back, or the result of deforestation (e.g. Mighall & Chambers 1995, Barbier & Visset 1997). However, the composition of the palaeochannel community (dominated by *Juncus* spp. with a limited presence of grasses) suggests that regeneration of vegetation has been adversely affected by anthropogenic activity as no regeneration of alder is evident and the community represents a degraded mire (Rodwell 1995).

In summary, habitat development in palaeochannel DC7 is initially restricted due to continual flow through the channel and backwater sediment deposition. The period of channel abandonment for palaeochannel DC7 was characterised by higher flood frequency and magnitude and climatic deterioration (Rumsby 1991, Mauquoy & Barber 1999b, Section 7.1.6) that was followed by a change to the fluvial regime and a reduction in planform channel change (Section 5.1.1). This reduction in flood frequency and magnitude combined with the plugging of the palaeochannel with sediment thus limited inundation in palaeochannel DC7 and encouraged autogenic vegetation succession. The character of palaeochannel habitat development reflects contemporary systems where hydroseral succession and terrestrialisation proceed following palaeochannel isolation due to alluvial plug development, fluvial incision and flow regulation (Bravard *et al.* 1986, Bornette & Heiler 1994, Marston *et al.* 1995, Bornette *et al.* 1998, Pokorny *et al.* 2000). In the case of palaeochannel DC7, isolation from high magnitude flood events was enabled by the rapid palaeochannel sedimentation and plugging. The development of a diverse alder carr

community (prior to anthropogenic disturbance) reflects the affects of reduced flood disturbance on floodplain biodiversity (cf. Marston *et al.* 1995).

7.2.4 Temporal habitat development for palaeochannel KW1

The model of palaeochannel habitat development for KW1 is illustrated in Figure 7.6. Channel abandonment occurred between 1771 and 1822AD as a result of an extensive lateral avulsion (Section 6.1, Fig 6.6A). High rates of infilling with fine, medium and coarse sands (facies Sp, Fig 6.10) characterised palaeochannel abandonment, potentially preventing the establishment of vegetation (Pautou *et al.* 1997, Amoros & Bornette 1999). Following avulsion the sediment facies Fl overlying the abandonment facies (Fig 6.11) indicate a steady reduction in the influence of the main channel, most probably linked to the creation of an alluvial plug at the upstream and downstream ends of the palaeochannel (Erskine *et al.* 1992). This allowed the establishment of a low energy backwater aquatic habitat (Fig 7.6, macrofossil zone 1 Fig 6.12). The initial vegetation community, with the presence of species including *Alisma plantago aquatica,* indicate an increase in organic matter accumulation and a degree of nutrient enrichment. The biotic response to the reduction in fluvial inputs is rapid, thus signifying the importance of the regeneration traits of the pioneer species (Van der Valk 1981, Townsend & Hildrew 1994) following fluvial transport of propagules into the habitat (Barrat-Segretain 1996).

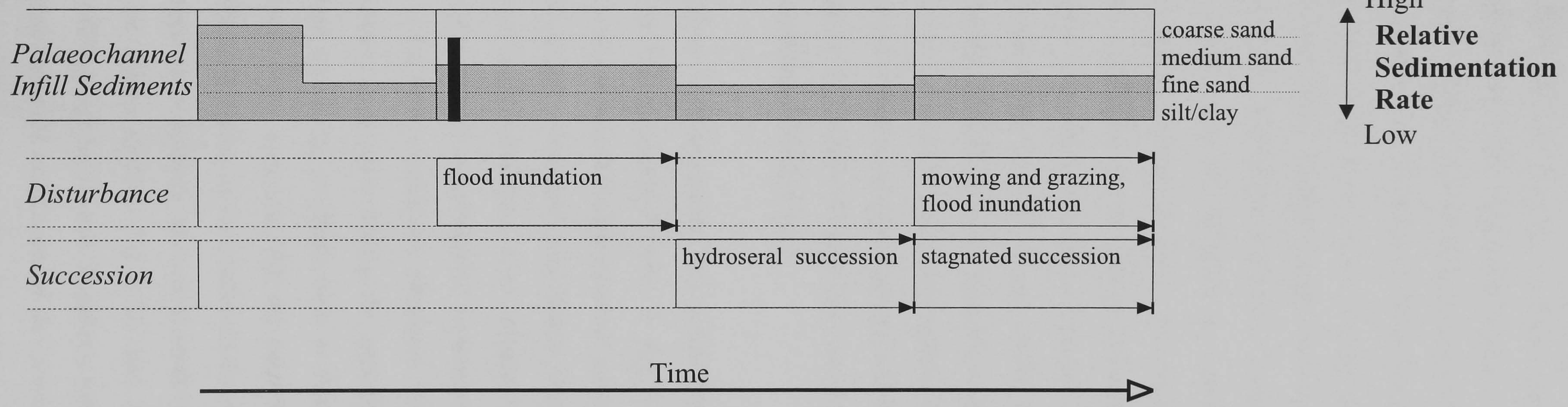
Vegetation community establishment is temporary due to a period of disturbance as the sediment facies reveal high magnitude flood inundation and the deposition of medium and coarse sands (Fig 6.10). Plant macrofossils from the palaeoflood sediments (macrofossil zone 2, p149) were not assessed due to the potential input of high proportions of *ex situ* vegetative matter during high discharge events (Amoros & Bornette 1999). However, the characteristics of the stratigraphy and the plant macrofossil record do indicate a reduction in vegetation cover and the potential scouring and degradation of species and seed banks. The destruction of pioneer vegetation implies that palaeochannel vegetation was not dense enough to provide a protective cover (Hawkins *et al.* 1997). Furthermore, the impact of flooding on the vegetation expresses the importance of post-abandonment processes on the palaeochannel biotic development. KW1 was abandoned as a result of a sinuous meander cut off which, according to previous models of palaeochannel development, results in the deposition of an

Figure 7.6

Model of the Temporal Development of KW1

Palaeochannel Habitat	backwater aquatic habitat, rapid coarse sediment infilling	restricted vegtation establishment, flood inundation	mesotrophic fen	wet meadow
Associated Macrofossil Zone & Species	1 *Potamogeton spp, Alisma plantago-aquatica, Daphnia*	2 *Juncus spp, Prunella vulgaris, Cerastium fontanum*	3 *Potentilla palustris, Carex spp, Alnus glutinosa*	4 *Phalaris cf arundinacea, Juncus spp, Urtica dioica, Glyceria fluitans*

Floodplain Processes



alluvial plug and progressive reductions in the influence of the main channel (Erskine *et al.* 1982, Amoros & Wade 1996, Qinghai *et al.* 1996a) and as also seen for palaeochannel DC7. The development of KW1, however, is marked by high magnitude flood inundation, sedimentation and scour. These post abandonment processes therefore have greater similarity with those experienced in braided systems (e.g. Bornette & Amoros 1991b, Pautou *et al.* 1997) than meandering, thus indicating that channel planform is not an accurate measure of palaeochannel sedimentation (cf. Brierley & Hickin 1991). Similar results were obtained by Bornette *et al.* (1998b) who found that classifying floodplain habitats in contemporary systems according to channel planform and regime was not sufficient in describing and explaining habitat functioning. Their research found that age, elevation, and location with respect to the active channel were also highly significant in determining fluvial dynamics and, hence, vegetation compositions. Similarly, the affects of flood inundation on the development of palaeochannel KW1 surmounted any affect of the initial planform morphology and fluvial regime. With respect to the chronology of the palaeofloods, the post abandonment flood inundation occurred only a short time following abandonment (Fig 6.10). The flooding, therefore, may be linked to a period of historical high magnitude flooding and climatic deterioration in northern England (Rumsby & Macklin 1994) which was also a factor in the avulsion which initially created the palaeochannel (Section 6.1).

Following flood disturbance the expansion of wetland vegetation and establishment of a mesotrophic fen type community occurs (Fig 7.6, macrofossil zone 3, Fig 6.12). The vegetation composition is interesting as it does not follow the same trend as was seen after the initial abandonment of the channel when an aquatic community established, when aquatic species exhibited rapid response when environmental conditions were suitable (Fig 7.6). Following the flood inundation, there is no recovery of a hydrophyte community as the palaeochannel habitat develops directly into a fen type community (Rodwell 1995). This response may be linked to extensive sedimentary deposition during the previous floods instigating rapid terrestrialisation and conditions not suited to plants such as *Potamogeton* spp. Furthermore, the low nutrient status of the habitat contrasts with the eutrophic sedge swamp habitat of palaeochannel DC7. The difference relates to inundation as the erosion of the pioneer aquatic community and the sedimentation of medium and coarse sands resulted in a low volume of organic material within the habitat (LOI - Fig 6.12) and hence the mesotrophic status of the fen. Therefore, the infilling and flood scour in palaeochannel KW1 brought about changes to both the physical and chemical conditions of the palaeochannel, affecting the contemporary and consequent composition of the vegetation community (Gleason 1927, Van der Valk 1981). The habitat template created by flooding thus controlled

the characteristics of habitat development (cf. Hupp & Osterkamp 1985, Kalliola & Puhakka 1988).

The most recent stage of development (Fig 7.6, macrofossil zone 4, Fig 6.12), which extends to the present palaeochannel surface, signifies a termination of floodplain fen development and a limit to vegetation succession. From the sedimentary data and from the modern day analogue, increases in overbank flows are evident from the Sh facies (Fig 6.11) as are anthropogenic impacts on the habitat. High magnitude inundation of KW1 may limit hydroseral succession as has been noted elsewhere by numerous researchers (e.g. Kalliola & Puhakka 1988, Bornette *et al.* 1994a, Amoros & Wade 1996). However, human impact also has to be accounted for and balanced against the effects of flooding (cf. Marston *et al.* 1995). In the case of KW1, the sandy substrate with low organic matter content, high water table and low vegetation cover suggest a low nutrient habitat and limited vegetation growth (Pinay *et al.* 2000). Conversely, the natural physical habitat template inferred by the sediments (cf. Resh 1994) does not correlate with the species composition of KW1, which indicate a eutrophic environment but with little corresponding increases in vegetation cover (Section 6.2.3). Therefore, the palaeochannel vegetation community infers nutrient enrichment, which can result from upstream catchment pollution sources deposited during flood inundation (Robach *et al.* 1997) of which none are known of presently or in the past 50 years (Environment Agency 1999), or agricultural activity (Craft & Casey 2000). The palaeochannel and terrace are both subject to livestock grazing whose influence on the composition of the vegetation community is reflected by the high tolerance levels of species present to agricultural disturbance. The relative influence of flood inundation and agricultural activity are difficult to resolve, however, it is certain that both are reflected in the species poor wet meadow and grassland habitat of palaeochannel KW1.

In summary, the development of palaeochannel KW1 is characterised by flood disturbance and limited organic matter accumulation, which determined the longevity of the pioneer aquatic community and the trophic status (and species composition) of wetland habitat establishment. The effects of flooding have been examined by Heiler *et al.* (1995) who also found that inundation "flushed out" biota and changed the nutrient status and character of floodplain habitats. However, in contrast to previous models of floodplain habitat development (e.g. Junk *et al.* 1989, Bornette *et al.* 1994a) flood inundation in palaeochannel KW1 did not reset the vegetation successional sequence due to extensive terrestrialisation restricting aquatic community establishment, although, flooding did alter the habitat

characteristics development through the removal of organic matter and modification of the trophic status.

7.2.5 Temporal habitat development for palaeochannel KW2

The model of temporal palaeochannel habitat development for KW2 is illustrated in Figure 7.7. Channel abandonment of the meander bend of palaeochannel KW2 occurred through local avulsion (Section 6.1). However, a period of channel rationalisation prior to complete abandonment is highlighted by the extensive coarse sediment deposits within a chute channel feature (Fig 6.13) on the inner meander bend (facies Sp, Fig 6.15). Radiocarbon dates from organic sediments which overlie the coarse sediment facies (Fig 6.2) indicate that channel abandonment occurred prior to 670-970cal.AD (Table 6.1). During abandonment, the sediment fills indicate high rates of sediment deposition within a slow flowing side arm, that remains connected to the main channel (Fig 6.16). Due to the dominance of coarse sediment inputs and, hence, the potential high proportions of *ex situ* plant macrofossils, assessment of the palaeochannel biotic characteristics is restricted. The macrofossil data suggest the initial presence of riparian vegetation (macrofossil zone 1, Fig 6.17), although it is not certain whether the data reflect *in situ* species or species from upstream within the catchment.

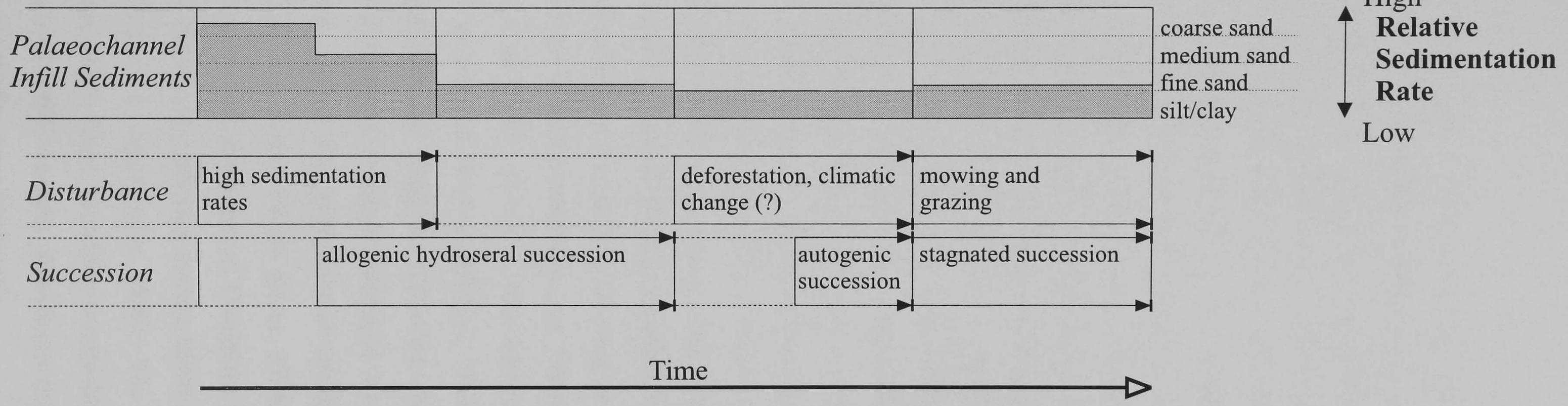
During the first stage of palaeochannel development the proportion of coarse sediment steadily declines (Table 6.6), with an associated rise in emergent vegetation and wetland species (zone 1, Fig 6.17). Subsequently, the establishment of woody vegetation is evident which, considering the water levels within the channel, will have established on the sandy deposits or point bar on the inner side of the meander bend. The woody species present, *Populus* and *Salix*, are known to rapidly colonise areas of bare sand (Pautou & Decamps 1985, Walker & Chapin 1986) to form a thicket type vegetation. The initial effects of the high sedimentation and continued inundation were, therefore, the provision of environmental conditions suitable for the establishment of *Salix* and *Populus*, which required both exposed sandy substrates and flood disturbance (Barnes 1997, Cordes *et al.* 1997). While the sedimentary inputs enabled allogenic succession (*sensu* Pautou & Decamps 1985) on the terrace surface, the decoupling between palaeochannel and active channel resulted in the establishment of aquatic and wetland species, reductions in sedimentation rates and increases

Figure 7.7

Model of the Temporal Development of KW2

Palaeochannel Habitat	**river side arm, riperian habitat**	**floodplain woodland with wetland sub-communities**	**initially degraded wetland and grass-land, followed by sedge swamp**	**wet meadow and species poor wetlands**
Associated Macrofossil Zone & Species	**1** *Glyceria fluitans, Juncus spp, Callitriche spp, Alisma, Populus spp*	**2** *Alnus glutinosa, Quercus spp, Sambucus nigra, Prunus spp*	**3** *Juncus spp, Glyceria fluitans, Carex spp, Poaceae*	**4** *Ranunculus repens, Rumex obtusifolia, Juncus spp, Cerastium fontanum*

Floodplain Processes



in organic matter accumulation. This indicates the commencement of autogenic change (cf. Hughes 1997) within the palaeochannel.

A continuation of woodland succession on the sandy deposits of the left channel side sees the colonisation of hardwood species and a shrub lower canopy layer (macrofossil zone 2, Fig 6.17 and 7.7). The establishment of floodplain woodland has two major implications. Firstly it represents floodplain woodland succession as seen in contemporary fluvial systems (e.g., Nanson & Beach 1977, Pautou & Decamps 1985, Marston *et al.* 1995) with development enabled by the initial establishment of shrub species on alluvial deposits, which created suitable conditions for the colonisation of a more mature and extensive woodland community. Secondly, the canopy, situated on the edges of the former channel, created microhabitat conditions with respect to shade and nutrient inputs (through organic deposition in the form of bud scales, fruits, wood and bark), within the palaeochannel. Consequently, the wetland community within the palaeochannel is sparse and composed of shade tolerant species with the absence of dominants such as Cyperaceae species and establishment of less aggressive species (Rodwell 1995). The palaeochannel vegetation community composition expresses the importance of life history traits in the development of wetland communities (Fastie 1995, Abernethy & Willby 1999) as, in this scenario, establishment requirements included moisture values and shade tolerance (cf. Van der Valk 1981). Therefore the biotic development reflects the results of high sedimentation rates during abandonment and subsequent undisturbed autogenic vegetation succession within the palaeochannel. Hardwood successions in floodplain forests have been observed in contemporary systems as resulting from river regulation, entrenchment and reduction in flood inundation (e.g. Bravard *et al.* 1986; 1997, Marston *et al.* 1995, Mendonca *et al.* 1997). Similarly, the biotic change in palaeochannel KW2 may also be the result of reduced flood inundation. These fluvial dynamics link to the natural dynamics of channel change along the Kellwood reach of the River Irthing (Section 7.1.4) whereby extensive lateral avulsions increased the distance between palaeochannel and active channel and reduced the probability of inundation (cf. Heiler *et al.* 1995). The fluvial dynamics of the Bogue Chitto River, USA, created environmental disturbance gradients and subsequent spatial patterns of floodplain woodland species with *Salix* and *Populus* in areas of high disturbance and high sedimentation rates, and *Quercus* in protected, elevated areas (Robertson & Augspurger 1999). The spatially organised woodland establishment on the Bogue Chitto River, therefore, is equivalent to the temporal woodland establishment on the terrace of KW2, whereby disturbance from fluvial inputs has reduced over time, allowing hardwood woodland establishment.

A decline in arboreal species is evident in the midpoint of the fossil record (macrofossil zone 3, Fig 6.17 and 7.7). The sedimentary context for the decline depicts a reduced vegetation cover (LOI, Fig 6.17). This may relate to a change in environmental conditions (previously determined by the woodland habitat) following canopy reduction or potential increases in overbank or runoff inputs within the palaeochannel. Therefore, two main possible reasons for biotic change are proposed, which may have acted independently or in conjunction. The woodland disappearance was either anthropogenically induced, *via* deforestation, or the result of natural external inputs such as changes to the water table depth, flood inundation or climatic conditions. Piegay (1997) observed floodplain woodland decline following a drop in water table levels, while Marston *et al.* (1995) noted that *Populus* replaced *Quercus* on well drained soils. A drop in water table may have occurred at KW2 considering the extensive avulsions experienced along the reach which will have extended the distance between the palaeochannel and contemporary channel. However, there is little evidence for woodland replacement with shrubs and arboreal species more suited to lower moisture conditions (this issue is further addressed below). The fine silts and clays (facies Fsc, Fig 6.16), which are laterally extensive within the palaeochannel suggest overbank or runoff sedimentation. However, these are limited to the palaeochannel habitat (Fig 6.15), therefore the effects may not have affected the vegetation on the terrace surface. Furthermore, the fill sediments exhibit no evidence for high magnitude flood inundation (Fig 6.15).

The period represented by the woodland decline, although not dated, is assumed to have occurred 100-300 years following channel abandonment (prior to 670-970cal.AD), based on the time taken for floodplain woodland to establish (Robertson & Augspurger 1999, Sakai *et al.* 1999). Furthermore, a radiocarbon date obtained from organic sediment from the palaeochannel fill places the later part of the early stages of development within KW2 to 880-1170 cal.AD (Fig 6.2). This places the woodland decline in the Medieval period, when monastic settlements were expanding in northern England with resulting increases in agricultural activity and deforestation (Rollinson 1978, Winchester 1987, Barber *et al.* 1994b). Significantly, upstream of the Kellwood and Dovecote sites, Lanercost Priory was constructed in the mid 12th Century, while castles were also constructed at nearby Irthington and Brampton (Rollinson 1978). The use of local woodland resources therefore will have increased greatly. Therefore, the woodland decline, although localised, may be attributed to the increased magnitude of anthropogenic activity in the region during the Medieval period or potentially to a possible drop in water table following channel avulsions.

With respect to hydrological conditions within the palaeochannel and associated terrace, there is no evidence for an extensive return of woodland species following the decline. The reason for an absence of woodland regeneration may not be directly linked to hydrological change but could be attributed to the environmental conditions within the palaeochannel and terrace. The primary woodland developed on bare coarse sediments, following channel abandonment which provided the necessary conditions for subsequent woodland succession (Pautou & Decamps 1985, Walker & Chapin 1986). The first species therefore established due to the characteristics of the substrate and water table height, and the absence of shade or competition. Conversely, following deforestation, the terrace surface will have been covered in an organic rich soil layer and due to the extensive lateral avulsions of the channel, the palaeochannel became isolated from the active channel, reducing the probability of coarse sediment deposition. The conditions for woodland colonisation on the terrace, therefore, had been substantially modified from when woodland was first established and may help to explain the lack of regeneration following its decline. The absence of regeneration may also, however, be linked to anthropogenic activity.

Following disturbance, the vegetation data reveal the response of the wetland vegetation (Fig 7.7). Initially the reduction in woodland resulted in a sparse vegetation cover, however, the organic content of the sediments steadily increases with the presence of the organic facies C (overlying the clay and silt Fsc facies, Fig 6.16) and establishment of a sedge swamp type habitat (macrofossil zone 4, Fig 6.17) within the palaeochannel. This change suggests limited fluvial inputs, as the habitat development denotes the first stages of autogenic hydroseral succession (Bornette *et al.* 1998a). The final stages of vegetation development in the palaeochannel denote a termination of autogenic succession as the sedge swamp is replaced by wetland grasses and wet meadow species (Craft & Casey 2000). The vegetation present primarily signifies a waterlogged fertile habitat, with many of the species tolerant of livestock grazing (Grime 1998). This reflects the characteristics of the present day habitat where the palaeochannel is waterlogged due to surface water and ground water inputs (Brown 1997a), decoupled from the main channel and subject to agricultural activity.

In summary, the pattern of KW2 palaeochannel development parallels contemporary systems experiencing high rates of sedimentation followed by a decline in flood disturbance (e.g. Pautou & Decamps 1985). The characteristics of habitat development were initially controlled by high rates of palaeochannel sedimentation following abandonment. Subsequent habitat development was determined by the isolation of the palaeochannel, enabled by lateral channel avulsions which have predominated late Holocene valley floor evolution (Section

6.1). Therefore, palaeochannel development, up to the time of woodland decline, is directly related to geomorphological processes and nature of floodplain evolution along the Kellwood reach of the River Irthing (cf. Hupp & Osterkamp 1985; 1996, Bravard *et al.* 1997).

7.3 Characteristics and Patterns of Temporal Palaeochannel Development Evident at the Dovecote and Kellwood Sites

The reconstruction of floodplain palaeochannel environments along the River Irthing valley floor has elucidated a number of issues surrounding the external and internal controls of habitat development and system response to environmental change. These issues comprise the rates of vegetation development (Section 7.3.1), the impact of flooding (Section 7.3.2) and the effect of the former fluvial regime on habitat development (Section 7.3.3). Each is discussed below. Finally, a summary model of palaeochannel development derived from the reconstructions of the River Irthing palaeochannels has been constructed (Section 7.3.4).

7.3.1 Temporal aspects of vegetation development

It has been asserted that changes to the species composition of wetlands occur as a result of changes to the physical or chemical conditions at the site (Gleason 1927), while the process of vegetation succession is also enabled through modification of environmental conditions (Miles 1987). These theories of biotic change can be used to explain the rapidity of vegetation development within River Irthing palaeochannels. The successional sequence in palaeochannel DC7, for example, developed from an aquatic lentic habitat to alder carr in less than 150 years, while palaeochannel KW2 also saw rapid succession from a riparian system to hardwood floodplain woodland. These findings contrast with previous palaeoecological research undertaken on floodplain wetlands which showed that vegetation communities persisted for longer periods of time. Wells & Wheeler (1999), for example, found that a fen community persisted unchanged for 800 years in a floodplain mire, whereas Thoms (1999) found little vegetation change within a metre of core covering 3000 years. These studies exemplify floodplain habitats whose physical habitat conditions are solely determined by *in situ* organic matter accumulation and high water tables. Conversely, floodplain palaeochannels can experience high rates of sediment infilling during and following channel abandonment which enable rapid progression from an aquatic habitat to floodplain mire (e.g. Sections 7.2.3 and 7.2.5). Consequently, organic matter accumulation alongside low magnitude runoff or inundation deposits result in changes to the physical and

chemical habitat characteristics (Hughes 1997) and can provide propagule transport mechanism for the introduction of new species (Amoros & Bornette 1999).

This type of rapid vegetation succession is in accordance with a succession model (Section 2.1.1) which predicts that species establish following the creation of suitable habitat conditions, thus enabling vegetation composition change within communities (Van der Valk 1981, Amoros & Wade 1996). Such biotic change is evident when alder carr communities succeed sedge swamp *via* the creation of hummocks onto which *Alnus* seeds can establish (Section 7.2.3, Pokorny *et al.* 2000). Similarly, the initial stage of thicket development on a sandy terrace produces a thin soil layer suitable for floodplain hardwood species to establish (Section 7.2.5, Pautou & Decamps 1985). The changing of environmental properties which enables a biotic response (according to the species life history traits) results in autogenic vegetation change and, ultimately, in hydroseral succession (Van der Valk 1981). This model of vegetation development, however, only applies to two of the five palaeochannels analysed (DC7 and KW2) for the present research, neither of which were subjected to frequent, high magnitude flood inundation after the commencement of hydroseral succession (Fig 7.5 and 7.7). Therefore, in floodplain habitats subjected to disturbance regimes, vegetation succession models based on autogenic development, such as that developed by Van der Valk (1981), are not always applicable (Bornette *et al.* 1994c).

7.3.2 The impact of flooding on palaeochannel development

The reconstruction of the rates and characteristics of palaeochannel infilling and development of facies models has revealed the presence of palaeoflood horizons (e.g. Fig 5.13 and 5.19) and determined the relative influence of the active channel on the palaeochannel. A synthesis of sedimentological data with the plant macrofossil evidence for biotic change and vegetation succession revealed that the effects of fluvial inputs on palaeochannel habitat fall into two divisions; one reflecting limited fluvial inputs and the other reflecting continual flood disturbance.

The reconstruction of palaeochannels subjected to high magnitude flood disturbance has elucidated the influence of inundation on biotic change. The significant effect of inundation on the palaeochannel vegetation composition was the resetting and stagnation of hydroseral succession. This follows trends seen in contemporary systems (e.g. Kalliola & Puhakka 1988, Bornette *et al.* 1994a; 1996) and models of flood impact which predict the resetting or rejuvenation of hydroseral succession (Amoros & Bornette 1999). The continuation of high

magnitude flooding disturbance along the River Irthing floodplain is linked to the characteristics of valley floor evolution. For example, limited fluvial incision and a tendency towards lateral channel change can encourage flood inundation and associated vegetation destruction and scour.

Contemporary studies which address the relationship between vegetation succession and the fluvial regime have been limited to timescales of up to 10 years (e.g. Bornette *et al.* 1994a, Heiler *et al.* 1995, Bornette & Amoros 1996). However, the timescales afforded by palaeochannel fill sediments have enabled the long term reconstruction of floodplain communities over longer timescales and have determined that the effects of inundation can persist over timescales of 10^2 years (Sections 7.2.1 and 7.2.4).

Palaeochannel development where high rates of sediment infilling are followed by a reduction in sedimentation, is characterised by autogenic hydroseral succession. This form of habitat development is comparable to floodplain habitats where flooding has been artificially reduced, through fluvial entrenchment following flood control or dam construction for example (Bravard *et al.* 1986, Marston *et al.* 1995, Begg *et al.* 1998). An absence of flooding within River Irthing palaeochannels, however, was linked to the plugging of abandoned channel and the form of floodplain evolution through extensive lateral channel avulsions (see Sections 7.2.3 and 7.2.5). The biotic response therefore was related to the characteristics of valley floor evolution and resulting fluvial dynamics (Bravard *et al.* 1997) as opposed to direct river regulation.

7.3.3 The effects of the former channel regime on floodplain habitat development

Amoros & Wade (1996) discuss the effect of channel abandonment type, between former meandering and braided systems, on the subsequent development of palaeochannel vegetation. They maintain that, as a result of sinuosity reductions, change occurs rapidly in meandering systems; however in braided systems change is more progressive due to the continued influence of the main channel. Reconstruction of the River Irthing palaeochannels indicated the significance of the relative location of abandoned and active channel. Sediment fills demonstrated that acute angles, at the upstream connection, between abandoned and active channel (e.g. palaeochannel DC4 and DC7-Fig 5.1) could encourage the deposition of an alluvial plug (Erskine *et al.* 1992, Brown 1997a). The main affect of alluvial plug deposition comprised the decoupling between palaeochannel and active channel which

reduced the sedimentation rate and, consequently, created ambient conditions for the establishment of aquatic and wetland vegetation. Sediment facies models for the River Irthing palaeochannels illustrate distinct infill sequences that follow a pattern of sediment fining up profile following progressive decoupling over time (e.g. Figs 5.11, 5.23 and 6.15). However, increases in sedimentation rates up profile (e.g. Fig 5.17) and the presence of coarse sediment palaeoflood horizons are evident in three of the five palaeochannels (DC2, DC4 and KW1) signifying the importance of *post-abandonment* processes on the nature of palaeochannel development. Furthermore, no correlation exists between the original sinuosity of the palaeochannels and the characteristics of sedimentation.

These results correspond with the findings of contemporary researchers (e.g. Hupp & Osterkamp 1985, Bornette *et al.* 1998b) who have observed that it is not only the creation of geomorphological forms that influence vegetation development, but the subsequent balance of hydrological processes. Furthermore, the findings have implications with reference to the analysis of palaeochannel fill sediments. As discussed by Bridge (1985, 1993) and Hickin (1993) floodplain sedimentation cannot be determined by channel pattern or the former fluvial regime. The complex palaeochannel fills seen from the present data emphasis the temporal and spatial variability in of sedimentation patterns which are linked to post abandonment flood disturbance and the characteristics of valley floor evolution.

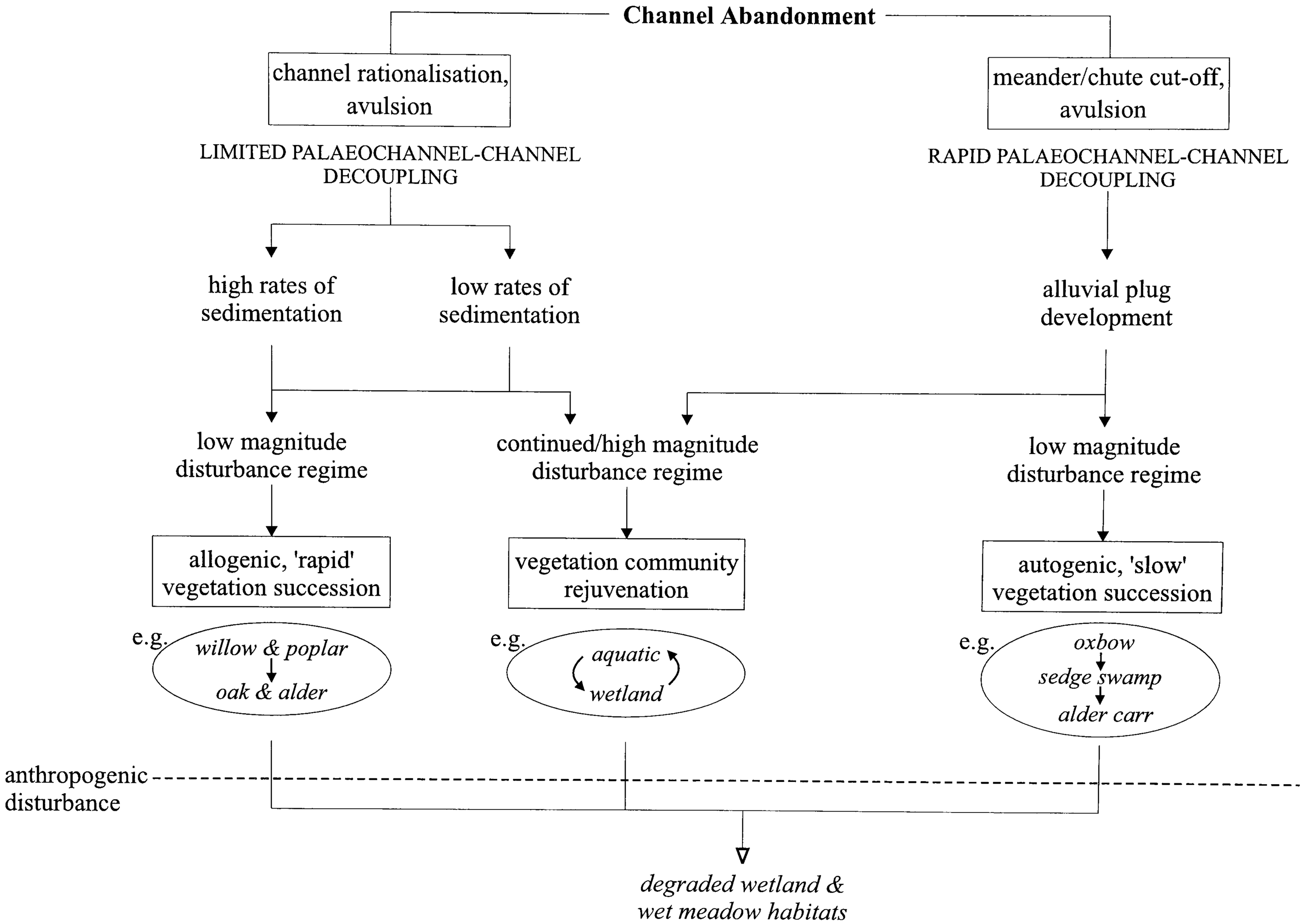
7.3.4 Summary model of floodplain palaeochannel development

A summary model of floodplain palaeochannel development, based on the reconstruction of palaeochannel habitats along the floodplain of the River Irthing is shown in Figure 7.8. The model divides the process of palaeochannel development into two stages. The first stage determines the primary characteristics of palaeochannel habitat establishment, based upon the channel abandonment processes and the consequent rates of sediment infilling. The second stage of palaeochannel habitat development is determined by the disturbance regime whereby an absence of disturbance enables autogenic vegetation succession, the character of which is affected by the initial rates of palaeochannel infilling. In contrast, continued disturbance can restrict hydroseral vegetation succession resulting in the rejuvenation of palaeochannel communities and enabling the persistence of early successional communities. Disturbance can also alter the character of hydroseral vegetation succession via the modification of environmental conditions.

Summary Model of Floodplain Palaeochannel Development

(derived from River Irthing floodplain habitats)

Figure 7.8



The model emphasises the influence of both floodplain evolution and post-abandonment processes on the characteristics of floodplain habitat development (Hupp & Osterkamp 1985;1996, Bravard *et al.* 1997). The model also reflects the multiple routes of vegetation succession and the significance of the landscape context and environmental template on which vegetation communities develop (Bornette *et al.* 1994c, Resh *et al.* 1994, Townsend & Hildrew 1994, Fastie 1995) and exhibits the complex processes that determine the nature and occurrence of vegetation communities (Petts *et al.* 1992, Gurnell 1995). Notably, human impact supersedes all other external and internal controlling factors on palaeochannel habitat development.

7.4 The Application of Plant Macrofossil Analysis to Palaeochannel Habitat Reconstruction

The reconstruction of palaeochannel habitat development has been achieved through plant macrofossil analysis of alluvial sediments. The technique of plant macrofossil analysis has rarely been applied to floodplain habitats for two reasons i) the absence of well preserved organic sediments suitable for the preservation of seeds and ii) the questions surrounding macrofossil taphonomy. Problems associated with the preservation of plant macrofossils did not impact upon the present study due to the presence of several palaeochannel reaches containing organic rich sediments. Problems associated with the taphonomy of plant macrofossils were addressed through the evaluation of the sedimentological context of macrofossil deposition (cf. Collinson 1983, Warner & Barnet 1986, Abernethy & Willby 1999) and the habitat niche data for the plant species present.

One of the main concerns surrounding plant macrofossil taphonomy in alluvial sediments is the potential presence of allochthonous or *ex situ* seeds, transported into a habitat during overbank flows. This 'problem' for palaeoecological investigations into floodplain habitats is an essential factor in the functioning of riparian and wetland communities as the input of plant propagules instigates and sustains the high biodiversity of such habitats (Bornette *et al.* 1994c, Barrat-Segretain 1996, Amoros & Bornette 1999, Ward *et al.* 1999a). Therefore, it is accepted that a proportion of the seeds within the plant macrofossil record will be of extra-local origin. However, it is important to assess what proportion of seeds are *ex situ* and what proportion derive from *in situ* species in order to interpret the fossil record. The techniques used to address this issue for the present research included the analysis of each sedimentological context to determine the sedimentation rate and proportion of *in situ*

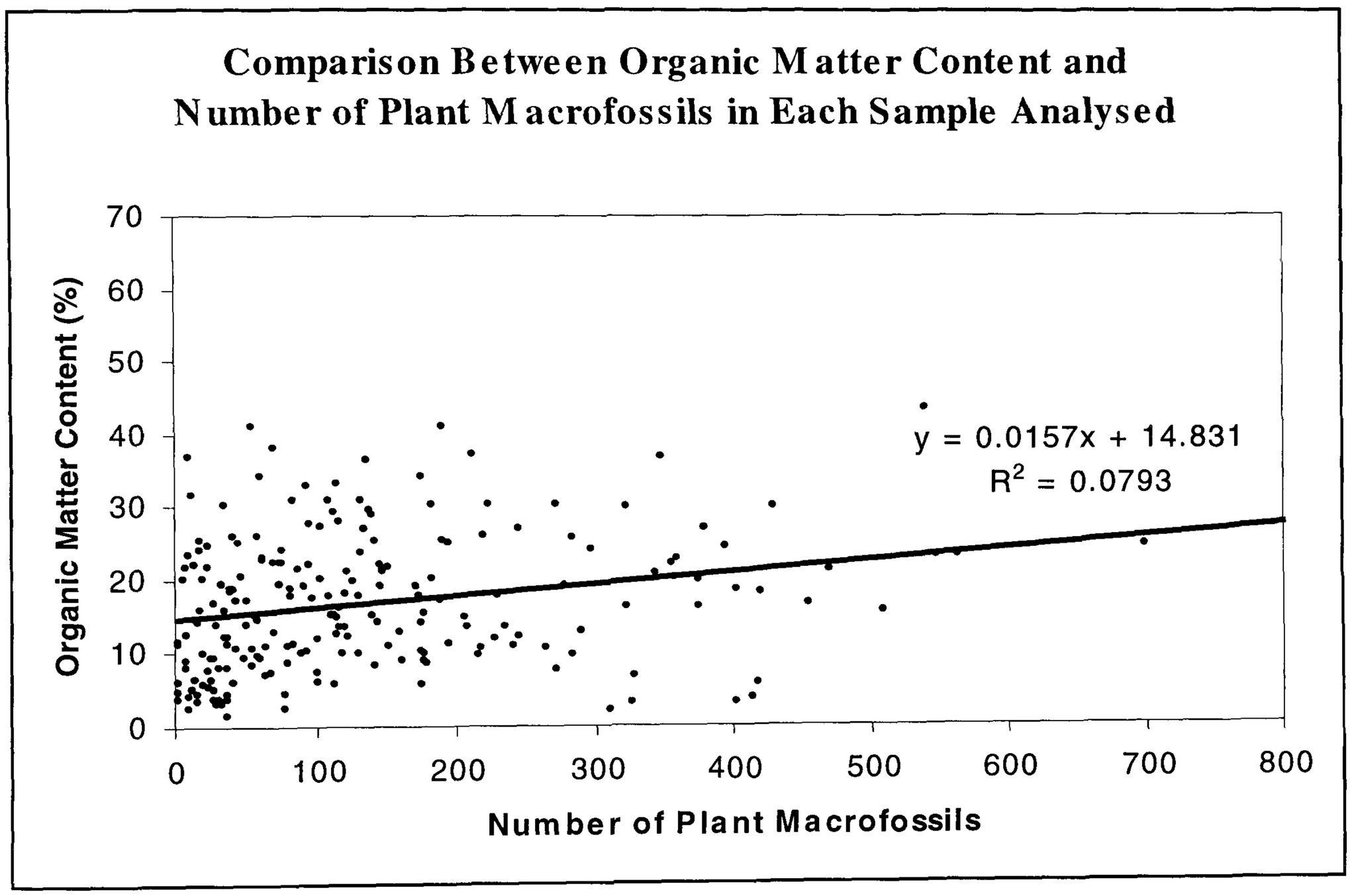
organic matter accumulation. The sedimentological context was also used to ascertain the character of the physical habitat in comparison with the species niche data to determine the probability of a species' presence.

Loss on ignition values provided an indication of the percentage of organic matter within each sample interval which could be used to assess the extent of organic matter accumulation. Collinson (1983) observed that the proportion of *in situ* macrofossils in a lake surface samples increased with distance from a stream source. Furthermore, lake habitats with little fluvial input are considered ideal for plant macrofossil investigations (Hannon & Gaillard 1997). It would be expected therefore that a correlation exists between the proportion of allochthonous sediment in a palaeochannel fill and the plant macrofossil record. Comparison of numbers of plant macrofossils with the percentage of organic matter however shows no correlation (Figure 7.9). The data from the River Irthing palaeochannels reveals that the number of plant macrofossils in alluvial sediments cannot be predicted from the proportions of organic matter. The reasons for this lack of correlation include differential seed productivity (cf. Harper *et al.* 1970), whereby species (e.g. *Potamogeton* spp., *Alisma plantago-aquatica, Callitriche* spp.), which can produce large numbers of seeds (e.g. Fig 5.14, 5.20) may not occur within a palaeochannel during a wetland or mire stage i.e. when the levels of organic material in the substrate are high. Furthermore, flood inundation can transport large numbers of seeds to a floodplain wetland (Amoros & Bornette 1999). Therefore, although organic matter content may be lower within palaeoflood horizons, numbers of seeds are sustained through *ex situ* inputs. These complexities which arise from sustained quantities of seeds in alluvial sediments combined with the problems created by differential seed production limit the extent to which plant macrofossil data can be analysed quantitatively. Therefore, in the absence of research into the quantitative significance of species present within the fossil record, interpretation concentrates on species presence and absence.

An important technique in the determination of macrofossil taphonomy therefore is the combination of sedimentological context and species niche data. From analysis of seed banks in riverine environments, Abernethy & Willby (1999) observed that 73-78% of seeds in heavily disturbed habitats derived from *in situ* established vegetation. This high correlation was attributed to the high productivity of species in frequently flooded environments; an adaptation to the habitat conditions. Their overall findings stated that 75-95% of seeds in wetland and riverine habitats derive from *in situ* vegetation or from the immediate surrounding floodplain habitat. These finding and those from the taphonomic studies of lake

and wetland habitats (Birks 1973, Drake & Burrows 1980, Greatex 1983, Warner & Barnet 1986, Section 2.4.4)) indicate that the majority of plant macrofossils derive from local vegetation. However, despite the acknowledgement that assessment of alluvial sediments and species ecology can aid in the interpretation of plant macrofossil data, more work in this area in the future is required in order to undertake quantitative analyses of plant macrofossils from palaeochannel environments.

Figure 7.9



Chapter 8

Conclusions and Future Research

Plant macrofossil analyses undertaken on a core from each of five late Holocene palaeochannels located along an extended reach of the River Irthing floodplain have provided a record of vegetation community composition change during the period of palaeochannel infilling. The data, combined with the sediment facies models for each channel, determined geomorphological, hydrological and ecological processes and interactions within each former river channel reach. The relative chronology and form of Holocene floodplain development was determined by floodplain mapping and topographic surveying while radiocarbon dating of palaeochannel fills and cartographic analysis ascertained periods of channel change dating to 2440-1920 cal. BC, 670-970cal. AD, 1410-1620 cal. AD and the late eighteenth to early nineteenth centuries. This application of high resolution palaeoenvironmental reconstruction techniques has elucidated (i) the physical and chronological context for valley floor development and (ii) the characteristics of palaeochannel habitat development. The results have enabled a conceptualisation of floodplain habitats (cf. Wheeler 1995) and will have enhanced our current understanding of floodplain dynamics (Henry & Amoros 1995).

8.1 Holocene Valley Floor Development along the River Irthing floodplain

The character of valley floor evolution along the extended study reach of the River Irthing floodplain was determined from geomorphological mapping, surveying and the lithostratigraphy of palaeochannel fill sediments. Investigations have ascertained that net incision occurred along the valley floor from the time of valley deglaciation, sometime between 16,000 to 13,000 BP, to the mid Holocene (*circa* 2440-1920 cal.BC). Thereafter, late Holocene channel and floodplain development along the downstream part of the reach was dominated by extensive lateral avulsions while the upstream section of the reach also experienced periodic channel avulsion. Organic palaeochannel fill sediments have been preserved across the valley floor due to a sustained high water table and limited lateral floodplain reworking. This form of valley floor evolution is rarely documented in upland British catchments (Tipping 1995a) where fluvial incision and reworking has typically restricted organic sediment preservation and limited the reconstruction of alluvial histories. However, preservation of organic palaeochannel fills has also been recorded in the middle

reaches of the North Tyne (Passmore & Macklin 1997) and its principle tributary, the River Rede (Moores *et al.* 1999), although the catchment conditions and valley relief are dissimilar to the River Irthing catchment. The character of planform channel change along the River Irthing is thought to be partly controlled by the incision of the river into the underlying bedrock and till (clays), although the influence of valley floor relief and catchment characteristics and land use may also have been significant influencing factors on floodplain evolution. Differences in the chronology and character of floodplain development between the upstream and downstream sections of the extended study reach emphasise the spatial variability of the fluvial system response to localised geomorphological controls (Macklin 1999, Passmore & Macklin 1997; 2000).

A preliminary chronology of terrace formation and channel abandonment along the northern side of the River Irthing Holocene valley floor has been obtained and compared with the timing of climatic deterioration, land use change and periods of fluvial incision and alluviation recorded in upland British river catchments. Radiocarbon dating and historic map data have identified four periods of channel abandonment: 2440-1920 cal. BC, 670-970 cal. AD, 1410-1620 cal. AD and 1771-1822 AD. The earliest period of channel change recorded delineates the boundary between the net incision and lateral channel change along the valley floor. This timing of channel abandonment correlates with episodes of gravel aggradation and fluvial incision elsewhere in upland British catchments. Similarly, the timing of the first millennium AD channel abandonment (670-970cal.AD) coincides with marked fluvial incision in the nearby River South Tyne catchment. However, accelerated human activity and landscape degradation associated with the Roman occupation is believed to have created antecedent conditions for the later first millennium fluvial regimes. Later channel change, during the late Medieval period, was coeval with climatic deterioration, as recorded from nearby ombrotrophic bog proxy climate data. More recent river planform changes, determined from historic maps, located two avulsion events occurring during the eighteenth and nineteenth centuries which coincide with documentary and geomorphological evidence for increased flood frequency and magnitude in British upland catchments. These results provide a preliminary chronology of floodplain evolution along the River Irthing floodplain. However, further dating control, than was obtained for the present research, is required to fully understand the processes of valley floor evolution along the reach. Radiocarbon dates from the basal and upper sediment fills of all palaeochannels across the valley floor are necessary to fully comprehend the chronology of Holocene floodplain development. Moreover, sedimentary data along the extended study reach was mainly confined to palaeochannel fills. To ascertain the character of aggradation and terrace formation,

sedimentological data from the Holocene terrace units is required. It is also acknowledged that the character of channel change and magnitude of fluvial incision at the site may be the result of localised responses to the fluvial regime and catchment characteristics. Therefore, a catchment wide investigation is necessary in order to further elucidate the timings and controls of valley floor evolution within the River Irthing catchment (Rumsby & Macklin 1994, Passmore & Macklin 1997, Howard *et al.* 1999).

8.2 Lithostratigraphy of Palaeochannel Sediments

High resolution sediment coring of five palaeochannel fills provided the geomorphological context for the reconstruction of palaeochannel habitat development by elucidating the relative sedimentation rates, changes in organic matter content, the height above the former river bed and the relative changes in water table heights. In addition, coarse sediment palaeoflood horizons were located in three of the palaeochannels analysed (palaeochannels DC2, DC4 and KW1). These horizons were limited in their spatial distribution within the palaeochannel fills due to the variability in sedimentation during inundation events. Without extensive coring, evidence for palaeofloods may not have been disclosed, consequently restricting interpretation of the palaeoecological data. This also highlights the limitations of coring techniques as opposed to exposed sections and trenching which provide high resolution lithostratigraphic data. The present research highlights the significance of floods in determining the character of vegetation community change (Section 7.3.2) and therefore emphasises the importance of a methodological approach that optimises the probability of obtaining evidence for high magnitude events within palaeochannel fill sediments.

Changes in sedimentation rates and infill characteristics through the sequences reflected the de-coupling between active channel and palaeochannel following abandonment. The facies sequences developed for the five palaeochannels along the River Irthing floodplain revealed the variability and complexity of sedimentation which, consequently, illustrated the difficulty of applying generalised facies models to palaeochannel fills (cf. Bridge 1993). Furthermore, although fining upwards sequences are evident in three of the five palaeochannels fills (cf. Allen 1965), two exhibit increases in sedimentation rates and grain size characteristics (cf. Erskine *et al.* 1992) in the upper parts of the sequence (palaeochannels DC4 and KW1). No link was evident between the sinuosity of the former channel and the character of infilling. Therefore, the results dispute previous work which maintained that palaeochannel infilling (and vegetation development) was mainly a function of the former channel regime (e.g. Amoros & Wade 1996) and support arguments that channel type is not the sole determinant

of infill characteristics (Bridge 1985; 1993, Brierley & Hickin 1991). However, evidence did suggest that the abandonment deposits within a palaeochannel fill could be influenced by the nature of channel change, as seen from the fill sediments of palaeochannel DC4. Here the acute angle between palaeochannel and the contemporary channel effected the rapid formation of an alluvial plug at the upstream end of the reach.

The influence of the underlying geomorphology of the abandoned channels was assessed from the three dimensional reconstruction of the former channel bed. Results determined the significance of depressions and geomorphological features within the former channel, on post abandonment sedimentation patterns.

8.3 Characteristics and Patterns of Mid to Late Holocene Palaeochannel Habitat Development

Palaeochannel habitats represent distinct ecological patches formed by the geomorphological processes of floodplain development (Petts *et al.* 1992). The methodological approach to this research enabled the reconstruction of detailed 'patch' development in response to the patterns and processes of floodplain development, while the spatial extent of peaty and organic sediments revealed the area of wetland, mire and aquatic communities within the abandoned channels. Moreover, the physical characteristics of the palaeochannel, as defined by the lithostratigraphic data, provided an indication as to the environmental gradients across the palaeochannel reaches. In palaeochannel DC2 for example, the reduction in fluvial inputs following channel abandonment was associated with the development of an environmental gradient. Here sediment fills and the plant macrofossil record suggested that a more dense vegetation established in the upstream part of the palaeochannel and a sparse vegetation cover in the downstream section as backwater inputs sustained an influence on species establishment. Vegetation gradients were also evident in palaeochannel DC4 where an oxbow lake type habitat established in the lee of the alluvial plug, while a more sparse vegetation cover established along the downstream end of the palaeochannel due to sustained backwater inputs and high sedimentation rates. Both of the above inferences are based upon both lithostratigraphic data and the plant macrofossil data. It is acknowledged however, that although the plant macrofossil data does represent localised vegetation, the actual spatial extent of the vegetation community represented is unknown. The spatial distribution can only be estimated from combining the macrofossil data and species niche data with sedimentological data to establish the probability of each species growing on the substrate in and around the former channel reaches. This is illustrated by palaeochannel KW2 where the

lithostratigraphy indicated areas of coarse substrate and areas of waterlogged peaty sediments while the macrofossil record contained species whose environmental preferences placed them within these spatial boundaries. Additional plant macrofossil cores from each palaeochannel reach analysed would also indicate the spatial representation of the plant macrofossils data.

Reconstructions of palaeochannel habitats show a link between vegetation change and the flood regime (Bornette & Heiler 1994), whereby hydroseral succession will proceed following the de-coupling of an abandoned channel with the main channel. Macrofossil records and palaeochannel fill sediments from palaeochannel DC7 for example, revealed undisturbed vegetation succession from an aquatic community to sedge swamp and, finally, alder carr. Conversely, hydroseral succession is limited by high magnitude flood inundation. Habitat development in palaeochannel KW1 was restricted by flooding. Here, the characteristics of post-flood palaeochannel vegetation development were affected by the restricted organic matter accumulation and displayed a mesotrophic status. Furthermore, vegetation community establishment and succession are influenced by the characteristics of palaeochannel sedimentation during and subsequent to abandonment. This was shown by the coarse sand abandonment facies of palaeochannel KW2 that provided a suitable surface for shrub vegetation development and subsequent floodplain deciduous woodland.

The analysis of late Holocene vegetation development along the River Irthing floodplain has been restricted by the absence of dating control for the upper sections of the palaeochannel fills although two of the palaeochannels, DC7 and KW1 were known to infill over the past 200 years on the basis of cartographic data. Furthermore, the two radiocarbon dates for palaeochannel KW2 indicate that the palaeochannel sequence spans over 300 years. Therefore, the timescales over which the data extends are known to be greater than 10^2 years. However, the determination of rates of infilling and timing of vegetation change and flood inundation necessitates further chronological control. Nevertheless, this study suggested that hydroseral succession may be relatively rapid where palaeochannels escape the impact of particularly high magnitude flood inundation. In contrast, restricted or stagnated vegetation succession occurs where palaeochannels are subjected to flood inundation over timescales of 10^2 years. The initial stages of palaeochannel development in the five reaches investigated were heavily affected by high sedimentation rates and exhibited vegetation community compositions to similar to contemporary floodplain wetland and aquatic habitats (Jones 1956, Wassen *et al.* 1990, Bornette *et al.* 1994a; 1994d; 1998a, Saarinen 1996). Plant macrofossil analysis of organic palaeochannel fills has extended the timescales of research and shown the affect on vegetation communities where flood disturbance is sustained or reduced in

frequency and magnitude over time. Palaeoflood horizons within the alluvial record of palaeochannel DC2 correlated with a reduction in aquatic vegetation, through terrestrialisation and possible vegetation destruction. Subsequently, the stagnation of vegetation succession resulted from sustained overbank sedimentation and flood inundation throughout the period of palaeochannel infilling.

The analysis and interpretation of plant macrofossil data was based upon species life history traits and habitat niche data derived from autoecological accounts. Recent research maintains that the majority of plant macrofossils in alluvial contexts derive from *in situ* species (Abernethy & Willby 1999). The evaluation of habitat niche data for the species within the fossil record also ascertained the probability of each species being found in the habitat as determined by the palaeochannel sediment fills. Furthermore, the taphonomy of plant macrofossils was considered through the analysis of the sedimentary context of macrofossil deposition which assessed the potential proportion of *ex situ* material entering the palaeochannel. Although these techniques were applied in this study to assess the taphonomy of plant remains, further work is necessary to fully understand the provenance of plant macrofossils in alluvial settings, which, to date, has attracted very little research. Consequently, evaluation of the fossil record during the initial stages of palaeochannel development was restricted due to high sedimentation rates and the potential input of *ex situ* macrofossils. Therefore, future research agendas need to address the representation of vegetation propagules in alluvial sediments (Abernethy & Willby 1999). This should be undertaken through the analysis of sub-fossils in surface samples in series of geomorphological settings. Such research should incorporate the physical factors of each habitat, including flood regimes and sedimentation rates and the landscape setting i.e. the position on the valley floor and within the catchment (cf. Amoros *et al.* 1987).

Although plant macrofossil analysis has provided detailed reconstructions of biotic change, interpretation of the macrofossil data was based upon species presence and absence, and qualitative observations of the data due to the ambiguities surrounding the quantitative significance of macrofossils within alluvial sediments. The data were not analysed quantitatively due to the limited understanding of the significance of each species presence within the fossil record. Further research is necessary to address the quantitative significance of macrofossil data, which should be based on seed production, preservation and dispersal mechanisms.

The spatial scale afforded by plant macrofossil investigations precluded evaluation of valley floor scale vegetation change, including assessment of Holocene human activity. Such data can be provided by palynological analysis of alluvial sediments as seen in the nearby Kirtle Water and North Tyne catchments (Tipping 1995b, Moores 1998). Data regarding human activity at the valley floor level within the River Irthing catchment, however, is lacking. Pollen analysis of palaeochannel fills has the potential to indicate valley floor changes in both vegetation and land use practices. Future palynological research is recommended in order to further analyse changes within the plant macrofossil record, such as the woodland decline observed in palaeochannel KW2, which may be the result of anthropogenic activity.

Finally, the effects of flood inundation on palaeochannel habitat development along the River Irthing valley floor has emphasised the significance of post-abandonment hydrological, geomorphological and biotic processes on vegetation community compositions. These interactions between physical and biotic processes in determining palaeochannel habitat characteristics stress the importance of applying a landscape context to the analysis of floodplain habitats. Previous research into floodplain restoration has observed problems relating to the inadequate knowledge of the affect of disturbance on floodplain habitat characteristics (Zedler & Weller 1990, Kauffman 1997). Therefore, as the aim of restoration is the reconstruction of the structure, functioning and dynamics of ecosystems (Henry & Amoros 1995), the plant macrofossil research could be pivotal to future floodplain habitat restoration and rehabilitation.

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Appendix 1 - Plant Macrofossil Species: Information and Issues of Identification

Species and authority	Common Name	Family	History and current distribution	Macrofossil identification source (see key below)
***Alismo plantago aquatica* L.**	Water plantain	Alismataceae	native, along Cumbrian valley floors and lowland	DA-UD
***Alnus glutinosa* L. Geartner**	Alder	Betulaceae	native, common throughout Cumbria	ARC. Includes seeds, catkin scales, bud scales and wood fragments
***Anthemis spp* L.**	Camomile	Asteraceae	scattered distribution in Cumbria	DA-UD
***Apium spp* L.**	Marshworts	Apiaceae	native, *A. nodiflorum* common throughout Cumbria	DA-UD
***Arenaria spp* L.**	Sandworts	Caryophyllaceae	most species native	Seeds identified to genus level only when slight degradation has occurred and positive identification to species level cannot be made.
***Arenaria serpyllifolia* L.**	Thyme leaved sandwort	Caryophyllaceae	native, present in River Irthing catchment	DA-UD
***Artemisia spp* L.**	Mugworts	Asteraceae	native & introduced, common in valley floors and lowlands of Cumbria	DA-UD
***Atriplex spp* L.**	Orache	Chenopodiaceae	most native, common throughout Cumbria	DA-UD
***Barbarea vulgaris* R. Br.**	Winter cress	Brassicaceae	native, common in river valleys and lowlands of Cumbria	DA-UD
***Betula pubescens* L.**	Downy birch	Betulaceae	native, common throughout Cumbria	ARC. Includes seeds and bracts
***Brassica spp* L.**	Cabbages	Brassicaceae	most native, scattered national distribution	DA-UD
Callitriche spp ***Callitriche stagnalis* Scop**	Water starworts	Callitrichaceae	native, two species common throughout Cumbria	Katz, Katz & Kipiani (1965)
***Calluna vulgaris* (L.) Hull**	Heather	Ericaceae	native, present in River Irthing catchment	DA-UD
***Caltha palustris* L.**	Marsh marigold	Ranunculaceae	common throughout Cumbria	DA-UD
***Carduus spp* L.**	Thistle	Asteraceae	native & introduced, limited distribution in Cumbria	DA-UD
***Carex spp* L.**	Sedge	Cyperaceae	native & introduced	DA-UD and Berggren (1969) includes seeds and utricles

Species and authority	Common Name	Family	History and current distribution	Macrofossil identification
***Carpinus betulus* L.**	hornbeam	Betulaceae	native, SE Eng., planted in rest of BI	Macrofossil remains consisted of bud scales, identified from Tomlinson (1985)
***Cerastium fontanum* Baumg**	Common mouse ear	Caryophyllaceae	native, common throughout Cumbria	DA-UD
Chara oospore		Charophytes	native, common throughout Cumbria	Katz, Katz & Kipiani (1965)
***Chenopodium album* L.**	Fat hen	Chenopodiaceae	common throughout Cumbria	DA-UD
***Chrysanthemum segetum* L.**	Corn marigold	Asteraceae	common throughout Cumbria	DA-UD
***Cicuta virosa* L.**	Cowbane, Mackenzie's water-hemlock	Apiaceae	native, present in south west Scotland and Northumberland	DA-UD
***Cirsium arvense* L. Scop**	Creeping thistle	Asteraceae	native, common throughout Cumbria	DA-UD
***Cirsium spp* L.**	Thistle	Asteraceae	native & introduced, common throughout Cumbria	Identified only to genus as seeds could not be distinguished between *Cirsium arvense, C. palustre* and *C. vulgare*
***Cladium mariscus* (L.) Pohl**	Great fen sedge	Cyperaceae	native, rare in Cumbria	DA-UD
***Convolvulus spp* L.**	Field bindweed	Convolvulaceae	native, common in river valleys and lowlands of Cumbria	Only identified from published reference material therefore was left at genus level.
***Eleocharis palustris* L. Roemer Schultes**	Common spike rush	Cyperaceae	native, common throughout Cumbria	DA-UD
***Epilobium hirsutum* L.**	Great hairy willowherb	Onagraceae	native, common in river valleys and lowlands of Cumbria	DA-UD
***Epilobium palustre* L.**	Marsh willowherb	Onagraceae	native, common throughout Cumbria	DA-UD
***Equisitum spp* L.**	Horsetails	Equisetaceae	native, some species common in Cumbria	Only identified from published reference material therefore was left at genus level
***Eriophorum spp* L.**	Cottongrass	Cyperaceae	native, some species common in Cumbria	DA-UD and Berggren (1969)
***Euphorbia spp* L.**	Spurges	Euphorbiaceae	native & introduced, scattered distribution in Cumbria	DA-UD
***Euphorbia cf helioscopia* L.**	Sun spurge	Euphorbiaceae	common in river valleys and lowlands of Cumbria	DA-UD

Species and authority	Common Name	Family	History and current distribution	Macrofossil identification
***Filipendula ulmaria* L. Maxim**	Meadowsweet	Rosaceae	native, common throughout Cumbria	ARC
***Galeopsis tetrahit* L. sensu lato**	Common hemp nettle	Lamiaceae	common throughout Cumbria	DA-UD
***Glyceria fluitans* L. R.Br.**	Floating sweetgrass	Poaceae	native, common throughout Cumbria	DA-UD
***Hieracium spp* L.**	Hawkweeds	Asteraceae	native & introduced, 62 species presently in Cumbria	Not enough reference material, considering the number of species presently in Cumbria, to identify to species level.
***Hippuris vulgaris* L.**	Mares tail	Hippuridaceae	native, few in Cumbria	Martin & Berkeley (1961)
***Hypericum spp* L.**	St John's wort	Clusiaceae	native, scattered national distribution	DA-UD
***Hypericum humifusum* L.**	Trailing St John's wort	Clusiaceae	native, present in River Irthing catchment	DA-UD
***Juncus spp* L.**	Rush	Juncaceae	native & introduced, common throughout Cumbria	ARC
***Lapsana communis* L.**	Nipplewort	Asteraceae	native, common throughout Cumbria	DA-UD
***Leontodon autumnalis* L.**	Autumn hawkbit	Asteraceae	native, common throughout Cumbria	DA-UD
***Lycopus europaeus* L.**	Gipsywort	Lamiaceae	scattered distribution in Cumbria	DA-UD
***Lynchis flos-cuculi* L.**	Ragged Robin	Caryophyllaceae	native, common throughout Cumbria	DA-UD
***Mentha aquatica* L.**	Water mint	Lamiaceae	native, scattered distribution in Cumbria	DA-UD
***Mentha arvense* L.**	Corn mint	Lamiaceae	native, scattered distribution in Cumbria	ARC
***Myosotis cf scorpioides* L.**	Forget me not	Boraginaceae	native, common throughout Cumbria	DA-UD
***Myriophyllum alterniflorum* DC.**	Alternate-flower water-milfoil	Haloragaceae	native, few in Cumbria	DA-UD, distinguishable by the smooth surface of the seed.
Nitella oospore	Alga		native, common throughout Cumbria	Katz, Katz & Kipiani (1965)
Nymphaceae	Lily	Nymphaceae	has been recorded in north west England	Seeds were too degraded to identify beyond a high taxonomic level
***Oxalis acetosella* L.**	Wood sorrel	Oxalidaceae	native, common throughout Cumbria	DA-UD
***Papaver rhoeas* L.**	Common Poppy	Papaveraceae	native, in arable areas of the Eden Valley	DA-UD

Species and authority	Common Name	Family	History and current distribution	Macrofossil identification
***Phalaris arundinacea* L.**	Canary grass	Poaceae	native, common throughout Cumbria	DA-UD and Musil (1980)
***Phleum pratense* L.**	Cat's tails	Poaceae	native, common throughout Cumbria	DA-UD and Musil (1980)
***Plantago major* L.**	Greater plantain	Plantaginaceae	native	ARC
***Plantago spp* L.**	Plantains	Plantaginaceae	native & introduced	Identified to genus level only when seeds too degraded to obtain species level
Poaceae	Grass	Poaceae	native & introduced	DA-UD and Musil (1980)
***Polygonum arenastrum* Boreau**	Equal leaved knotgrass	Polygonaceae	native, common throughout Cumbria	DA-UD
***Polygonum aviculare* L**	Knotweed	Polygonaceae	native, common throughout Cumbria	DA-UD
***Persicaria hydropiper* (L.) Spach (*Polygonum hydropiper* L.)**	Water pepper	Polygonaceae	native, common throughout Cumbria	DA-UD
***Persicaria maculosa* Gray (*Polygonum persicaria* L.)**	Redshank	Polygonaceae	native, common throughout Cumbria	DA-UD
***Polygonum spp* L.**	Knotgrasses	Polygonaceae	native, common throughout Cumbria	DA-UD
***Populus spp* L.**	Poplars	Salicaceae	native & introduced, common throughout Cumbria	Bud scales identified using Tomlinson (1985)
***Potamogeton spp* L.**	Pondweed	Potamogetonceae	mostly native, common throughout Cumbria	Martin (1951)
***Potentilla erecta* L. Raushel**	Tormentil	Rosaceae	native, common throughout Cumbria	DA-UD
***Potentilla palustris* L. Scop**	Marsh cinquefoil	Rosaceae	native, present in River Irthing catchment	DA-UD
***Prunella vulgaris* Hudson**	Self heal	Lamiaceae	native, common throughout Cumbria	DA-UD
***Prunus spp* L.**	Cherries	Rosaceae	native & introduced, common throughout Cumbria	ARC
***Prunus spinosa* L.**	Blackthorn	Rosaceae	native, common throughout Cumbria	DA-UD
***Quercus spp* L.**	Oak	Fagaceae	native & introduced, common throughout Cumbria	Includes acorns, bus scales (Tomlinson 1985) and wood.
***Ranunculus cf aquatilis* L.**	Water crowfoot	Ranunculaceae	present in the upper Irthing catchment	Published data

Species and authority	Common Name	Family	History and current distribution	Macrofossil identification
***Ranunculus repens* L.**	Creeping buttercup	Ranunculaceae	native, common throughout Cumbria	ARC
***Ranunculus spp* L.**	Buttercup	Ranunculaceae	native & introduced	Identified as Ranunculus spp when too degraded to identify to species level
***Raphanus spp* L.**	Radish	Brassicaceae	scattered, more common throughout Cumbria in the past	DA-UD
***Rubus fruiticosa* L.**	Bramble	Rosaceae	native & introduced in Cumbria	DA-UD
***Rumex acetosa* L.**	Common sorrel	Polygonaceae	common throughout Cumbria	DA-UD and Lousley & Kent (1981)
***Rumex crispus* L.**	Curled dock	Polygonaceae	common throughout Cumbria	DA-UD and Lousley & Kent (1981)
***Rumex obtusifolia* L.**	Broad leaved dock	Polygonaceae	native, common throughout Cumbria	DA-UD and Lousley & Kent (1981)
***Rumex sanguineus* L.**	Wood dock	Polygonaceae	native, common throughout Cumbria	DA-UD and Lousley & Kent (1981)
***Rumex spp* L.**	Dock	Polygonaceae	common throughout Cumbria	Seeds are identifies as Rumex spp when due to degradation of the seeds prevents positive identification to species level
***Salix spp* L.**	Willow	Salicaceae	native & introduced, 17 species and 20 hybrids in Cumbria	Includes bud scales and plant fragments. Identified from Katz, Katz & Kipiani (1965) & ARC
***Sambucus nigra* L.**	Elder	Caprifoliaceae	native, common throughout Cumbria	DA-UD
***Scirpus setaceus* L.** (*Isolepis setacea* **(L.) R. Br.**)		Cyperaceae	scattered distribution in England	DA-UD
***Scirpus spp* L.**	Wood club rush	Cyperaceae	native, scattered distribution in England	DA-UD and Berggren (1969)
***Sedum acre* L.**	Biting stonecrop	Crassulaceae	native, common throughout Cumbria	DA-UD
***Selaginella selaginoides* (L.) Beauv. ex Mart. & Schrank**	Lesser clubmoss	Selaginellaceae	native, present in the upper part of the River Irthing catchment	Katz, Katz & Kipiani (1965)
***Senecio spp* L.**	Fen ragwort	Asteraceae	native	Katz, Katz & Kipiani (1965), Martin & Berkeley (1961)
***Silene dioica* (L.) Clairv.**	Red campion	Caryophyllaceae	common in river valleys and lowlands in Cumbria	DA-UD
***Silene spp* L.**	Campions	Caryophyllaceae	native & introduced	The distinctive pattern enables identification when seeds are degraded, but only to genus level
Solanum spp ***Solanum dulcamara* L.**	Nightshades	Solanaceae	native & introduced, river valleys in Cumbria	DA-UD

Species and authority	Common Name	Family	History and current distribution	Macrofossil identification
***Sonchus asper* (L.) Hill**	Prickly sow thistle	Asteraceae	native, common throughout Cumbria	DA-UD
***Spergula arvensis* L.**	corn spurrey	Caryophyllaceae	native & introduced, common throughout Cumbria	DA-UD
***Staychs spp* L.**	Woundworts	Lamiaceae	native & introduced, common throughout Cumbria	DA-UD
***Stellaria media* (L.) Vill.**	Common chickweed	Caryophyllaceae	native	DA-UD
***Taraxacum spp* G.H. Weber ex Wiggers**	Dandelion	Asteraceae	native & introduced, 123 species present in Cumbria	Not enough reference material, considering the number of species presently in Cumbria, to identify to species level.
***Thymus spp* L.**	Thyme	Lamiaceae	native & introduced	Thymus spp produces very small sized fragile seeds which were not well enough preserved to obtain species level identification
***Tragopogon pratensis* L.**	Goats beard	Asteraceae	common in river valleys and lowlands of Cumbria	DA-UD
***Trifolium spp* L.**	Clover	Fabaceae	common throughout Cumbria	Identified to genus only due to the high number of species and the degradation of diagnostic features over time.
***Urtica dioica* L.**	Stinging nettle	Urticaceae	native, common throughout Cumbria	DA-UD

Modern Reference Material

DA-UD. Department of Archaeology, University of Durham reference material

ARC. Authors reference collection

Appendix 2 - Floodplain and Palaeochannel Core Logs

Dovecote DC1 Core Log

Depth	**Transition (from above)**	**Description**
0-23		compression
23-47		grey brown fine sandy clay silt, top soil
47-78	graded	light grey brown mottled fine clay silt, oxidised organics, charcoal flecks and seeds
78-92	graded	light grey brown fine sandy clayey silt, freq. organic inclusions
92-100	graded	some contamination, mottled orange grey fine sandy clay/silt
100-105	sharp	grey woody peat (falling out of core)
105-115	-	compression & contamination
115-123	graded	grey fine sandy clayey silt organic rich. Lots of macrofossils, (continuation from 105cm)
123-153	graded	dark brown peaty clay-silt occasional large wood fragments
153-200	sharp	sandy coarse gravel B axis=4cm

Dovecote DC3 Core Log

Depth	**Transition (from above)**	**Description**
0-16	compression	
16-29		medium brown fine sandy silt, top soil
29-48	graded	fine sandy silt, mottled grey brown, oxidised material, traces of fine laminations
48-59	graded	fine sandy clayey silt, mottled grey brown, oxidised material, traces of fine laminations
59-72	graded	clayey silt occasional charcoal, light brown grey, mottled
72-86	graded	grey clayey silt, some oxidised organics, mottling, occasional charcoal, some fine sand
86-98	sharp	peaty fine sandy silt, trace of clay, increased sand with depth, lots of organics, no mottling
98	sharp	silty fine-medium sand, grey brown, some lamination(?)
100-120		compression
120-148	-	interbedded (1)grey fine-medium sandy silts (2) grey/brown peaty fine sandy silt with organics sandy horizons @ 123-125, 133-135, 137-138
148+	sharp	coarse sandy gravel B axis 3cm

Dovecote DC5 Core Log

Depth	Transition (from above)	Description
0-46		dark brown, poorly humified silty peat, large intact organics in bottom 20cm, woody inclusions @ 40cm
46-61	graded	silty humified peat, high organic content, dark medium brown
61-82	graded	lighter medium grey-brown peaty silt
82-96	graded	laminated grey-brown fine sandy silt, large no. of organic inclusions
96-109	graded	medium grey-brown silty peat, some laminations
109-158	graded	fibrous medium/dark brown silty peat, 2cm layer of organic detritus @ 126cm
158-168	graded	light/medium brown peaty silt, fewer large organic inclusions
168-184	graded	organic medium grey-brown silt, some laminations
184+	sharp	gravel

Dovecote DC6 Core Log

Depth	Transition (from above)	Description
0-100		fine and medium sand with organic inclusions
100+	sharp	gravel

Dovecote DC8 Core Log

Depth	Transition (from above)	Description
0-100		medium sand with infrequent organic inclusions
100+	sharp	gravel

Kellwood KW3 Core Log

Depth	Transition (from above)	Description
0-80		medium fine sand
80-120	graded	peaty fine silt and sand
120+	sharp	gravel

Kellwood KW4 Core Log

Depth	Transition (from above)	Description
0-100		medium fine sand
100-130		fine sand with organic inclusions
130+	sharp	gravel

Kellwood KW5 Core Log

Depth	Transition (from above)	Description
0-40		top soil
40-120	graded	peaty fine sands and silts
120+	sharp	gravel

Kellwood KW6 Core Log

Depth	Transition (from above)	Description
0-100		top soil and fine sands
100-120		peaty silt and fine sand
120-230	graded	silty and fine sandy peat
230+	sharp	gravel

Kellwood KW7 Core Log

Depth	Transition (from above)	Description
0-25		peaty top soil
25-170		peaty fine sands and silts
170+	sharp	gravel

Kellwood KW8 Core Log

Depth	Transition (from above)	Description
0-30		top soil
30-160		fine sand with organic inclusions peaty horizons
160-170	sharp	coarse sand, wood above 170cm
170+	sharp	gravel

Kellwood KW9 Core Log

Depth	Transition (from above)	Description
0-135		fine and medium sand
135+	sharp	gravel

Appendix 3 Dovecote and Kellwood Palaeochannel Transect Sediment Data

Dovecote Palaeochannel 2 -DC2

Transect 1

Core	Depth	Transition (from above)	Description
0	0-10		depth to gravel
2	0-30		top soil
	30-70	G	mottled grey orange clayey silt, fine laminations, increasing grain size with depth
	70-85	G	medium brown silty fine sand, occasional very fine sand layers, few organic inclusions
	85-103	G	finely laminated fine medium sand, charcoal @ 90cm, some organic laminae
	103	S	gravel
4	0-35		top soil
	35-75	G	mottled grey orange clayey silt, fine laminations, increasing grain size with depth
	75-101	G	medium brown silty fine sands grading to fine medium sands
	101	S	gravel
6	0-35		top soil
	35-80	G	mottled grey orange clayey silt, fine laminations, increasing grain size with depth
	80-108	G	medium brown silty fine sands, occasional organic laminae, grades to fine medium sand
	108	S	gravel
8	0-35		top soil
	35-80	G	mottled grey orange clayey silt, fine laminations, increasing grain size with depth
	80-88	S	organic fine sandy silt
	88-105	G	medium brown fine medium sand
	105	S	gravel
10	0-30		top soil
	30-85	G	mottled grey orange clayey silt, fine laminations, increasing grain size with depth
	85-88	S	fine medium sand
	88-109	S	grey black peaty silt, occasional sand layers
	109	S	gravel
12	0-35		top soil
	35-80	G	mottled grey orange clayey silt, fine laminations, increasing grain size with depth
	80-95	G	grey black peaty silt, occasional sand layers
	95-100	S	fine medium sand
	100	S	gravel
14	0-35		top soil
	35-50	G	mottled grey clayey silt, fine laminations, increasing grain size with depth
	50-90	G	red grey fine sandy clayey silt
	90-100	G	red medium brown clayey sandy silt
	100	S	gravel
14.5	0-1.14		depth to gravel
15	0-1.13		depth to gravel
16	0-36		top soil, occasional small stones and charcoal, very friable soil
	36-50	G	clayey silty fine medium sand
	50	S	gravel

18	0-70		depth to gravel
20	0-104		depth to gravel
22	0-89		depth to gravel

Transect 2

Core	Depth	Transition (from above)	Description
0	0-35		top soil
	35-40	G	medium brown fine sand
	40-87	G	mottled grey clayey silt
	87-113	G	grey clayey silt
	113	S	gravel
2	0-35		top soil
	35-86	G	mottled grey clayey silt
	86-100	G	grey brown silt few organic inclusions
	100-109		fine - medium sand, some organic inclusions, 1 wood fragment @ 0.5cm diameter
	109	S	gravel
4	0-35		top soil
	35-74	G	mottled grey clayey silt
	74-90	G	grey clayey silt more silt with depth
	90-109	S	medium brown fine sand , increasing number of organic fragments with depth
	109	S	gravel
6	0-35		top soil
	35-68	G	mottled grey clayey silt
	68-68.1	S	fine sand band
	68.1-75	S	mottled clayey silt
	75-96	G	brown orange grey fine sandy silt, laminated
	96-98	S	sand layer
	98-113	S	medium brown fine sand some silt
	113	S	gravel
8	0-33		top soil
	33-78	G	mottled grey clayey silt, 0.1cm sand horizons @ 65, 67, 72 cm depth
	78-100	G	organic medium brown fine silty sand, increasing number of organic fragments near base, sand layer @92-93
	100-122		as above, coarsens with depth
	122	S	gravel
10	0-35		top soil
	35-68	G	mottled grey clayey silt
	68-122	G	grey brown silt, increasing number of organic fragments with depth, sand layers @ 104, 106
	122	S	gravel
12	0-32		top soil
	32-63	G	mottled grey clayey silt
	63-70	G	mottled grey frown fine sandy silt
	70-88	G	fine sand, some organic inclusions, coarsens with depth
	88	S	gravel
14	0-35		top soil
	35-67	G	mottled grey clayey silt, sand layer @ 45cm
	67	S	gravel
16	0-35		top soil
	35-84	G	mottled grey clayey sandy silt
	84-89	G	fine silty sand

	89-96	G	fine - medium sand
	96	S	gravel
16.5	0-70		depth to gravel
17	0-20		depth to gravel
18	0-22		top soil
	22	S	gravel
20	0-16		depth to gravel
22	0-5		depth to gravel
24	0-6.1		depth to gravel

Transect 3

Core	Depth	Transition (from above)	Description
0	0-35		top soil
	35-69	G	grey/orange mottled clayey silt
	69-70	S	grey orange fine sand
	70-76	S	grey orange fine sandy silt
	76-100	G	laminated medium - fine sand
	100	S	gravel
2	0-34		top soil
	34-75	G	grey/orange mottled clayey silt
	75-85	S	grey clayey silt
	85-95	G	grey silt
	95-100	G	medium - fine sand
	100-117	G	medium - coarse sand
	117	S	gravel
4	0-35		top soil
	35-84	G	grey/orange mottled clayey silt
	84-97	G	grey brown silt
	97-100	G	fine sand
	100-104	G	medium sand
	104	S	gravel
6	0-35		top soil
	35-72	G	grey/orange mottled clayey silt
	72-90	G	grey brown silt, some organic inclusions
	90-100	S	medium - fine sand, some fine gravel
	100-109	G	medium - coarse sand
	109	S	gravel
8	0-20		top soil
	20-72	G	grey/orange mottled clayey silt
	72-116	G	grey brown silt
	116-126	G	medium brown fine sand, some woody fragments
	126	S	gravel
10	0-35		top soil
	35-82	G	grey/orange mottled clayey silt
	82-100	G	grey brown silt, increasing organic inclusions with depth
	100-123		medium brown fine silty sand
	123-151	G	organic fine sandy silt
	151	S	gravel
12	0-35		top soil
	35-72	G	grey/orange mottled clayey silt
	72-116	G	grey brown fine sandy silt, increasing organic fragments with depth, especially bottom 10cm
	116-118	S	medium sand

	118-124	S	medium brown fine sandy silt
	124-125	S	medium sand
	125-150	S	medium brown fine sandy silt
	150	S	gravel
14	0-35		top soil
	35-56	G	grey/orange mottled clayey silt
	56-69	G	grey clayey silt
	69-82	G	medium brown fine sandy silt, incr. organic fragments, wood fragment @ 82cm
	82-118	G	medium brown silt
	118-123	S	medium - fine sand
	123-150	S	medium brown fine sandy silt
	150	S	gravel
16	0-40		top soil
	40-50	S	fine gravel with coarse - medium sand matrix
	50-70		mottled grey orange clayey silt
	70-100	G	medium brown fine sandy silt
	100-121	S	medium brown silt
	121-122	S	fine sand
	122-123	S	medium brown silt
	123-124	S	fine sand
	124-150	S	medium brown silt
	150	S	gravel
18	0-36		top soil
	36-46	S	fine gravel with coarse - medium sand matrix, 3cm B axis
	46-72	S	mottled grey orange clayey silt
	72-86	G	grey brown silt
	86-110	G	medium brown silt organic inclusions near base
	110-138	G	unconsolidated medium sand
	138	S	gravel
18.5	0-91		depth to gravel
19	0-56		depth to gravel
20	0-35		top soil
	35-78	S	fine gravel with coarse - medium sand matrix
	78	G	gravel
22	0-25		depth to gravel
24	0-25		depth to gravel
26	0-8.5		depth to gravel
28	0-13		depth to gravel

Transect 4

Core	Depth	Transition (from above)	Description
30	0-30		top soil
	30-50	G	grey brown medium sand, some oxidised organics
	50-83	G	orange medium sand, charcoal @ 80cm
	83-90	G	grey medium sand
	90-100	S	coarse sand
	100-150		coarse sand, gravel @ 110, organic fragment @ 140cm
	150	S	gravel
28	0-18		top soil
	18-30	G	brown grey fine sand
	30-50	G	fine sand
	50-80		coarse sand, occasional fine gravel (axis 2cm)

	80	S	gravel
26	0-20		top soil
	20-50	G	brown mottled clay with occasional charcoal and oxidised organics
	50-70		light brown sand, occasional charcoal
	70-83	G	grey brown sand, occasional gravel and oxidised organics
	83	S	gravel
24	0-33		top soil
	33-42	G	grey mottled clayey silt
	42-50	S	medium - fine sand
	50-84	G	fine - medium sand
	84-94	S	coarse sand
	94	S	gravel
23	0-122		depth to gravel
22	0-22		top soil
	22-50	G	brown clay with occasional charcoal and oxidised organics
	50-65		light brown clay
	65-100	S	grey fine sand, large root fragment @ 85cm
	100-105		light brown clayey silt
	105-125	G	fine sand
	125-140	G	coarse sand with occasional gravel and charcoal
20	0-32		top soil
	32-88	G	grey mottled clayey silt
	88-100	G	brown grey clayey silt, increasing organic inclusions near base
	100-110		light brown silt, few organic inclusions
	110-120	G	medium fine sand, silt layer @ 115
	120	S	gravel
18	0-40		top soil
	40-70	G	light brown mottled clay
	70-100	G	brown grey silty clay, occasional charcoal and organics
	100-112		coarse sand and gravel
	112	S	gravel
16	0-36		top soil
	36-82	G	grey mottled clayey silt
	82-100	G	grey brown silt, increasing number of organic fragments near base
	100-134		medium brown fine sand, coarsens with depth, wood fragment @ 118cm, silt layers @ 110, 112cm
14	0-40		top soil
	40-70	G	dark brown, mottled clay
	70-90	G	small laminations of silt and clay levels, darker brown, lots of oxidised material
	90-110		brown grey silt
	110-111	S	light brown sandy silt
	111-135	S	grey brown sandy silt, finer 110-130, occasional charcoal throughout
	135	S	gravel
12	0-36		top soil
	36-85	G	mottled grey clayey silt, increasing silt content with depth
	85-100	G	grey brown silt, some organic inclusions
	100-137		medium brown fine sandy silt, coarsens to silty sand, sand layers @ 116, 126
	137	S	gravel
10	0-40		top soil
	40-70	G	mottled light brown clay
	70-90	S	brown grey, silty clay, occasional charcoal and organics, increasing number of organics with depth (80-90)
	90-100	G	grey brown silt, occasional organics

	100-120		bands or silt/sand, dark grey, abundant organics and charcoal
	120-130	G	grey brown silt
	130	S	gravel
8	0-37		top soil
	37-82	G	mottled grey clayey silt, increasing silt with depth
	82-100	G	grey brown silt, occasional organic inclusions, increasing number with depth
	100-129		medium brown fine silt, coarsens to fine sandy silt, few organic inclusions
	129	S	gravel
6	0-38		top soil
	38-70	G	mottled grey clayey silt
	70-100	G	grey brown silt, few organic inclusions
	100	S	gravel
5	0-36		top soil
	36-63	G	medium brown clayey sand, large wood fragment @ 60cm
	63-100	S	medium grey brown silt, few woody inclusions, some sand content near base
	100-120		fine sandy silt, coarsening to silty sand, seeds @ 110
	120	S	gravel
4	0-40		top soil
	40-60	G	light brown mottled clay
	60-85		grey brown silt, lots of organics, large charcoal fragments @ 75cm, (3cm band)
	85	S	gravel
3.5	0-49		depth to gravel
3	0-8		depth to gravel
2	0-6		depth to gravel
0	0-2		depth to gravel

Transect 5

Core	Depth	Transition (from above)	Description
0	0-35		top soil
	35-45	G	fine gravel, sandy matrix, occasional organics
	45-50	G	finer sand, still few gravel inclusions
	50-64		fine sand, occasional gravel, and organics
	64-79	G	light brown, medium fine sand
	79	S	gravel
2	0-19		top soil
	19-33	S	medium brown silty sand
	33-41		orange brown silty sand
	41-50	S	light brown medium fine sand
	50-90		fine medium sand, charcoal @ 65cm
	90-115	S	coarse sand, few gravel inclusions (axis 3cm)
	115	S	gravel
4	0-31		top soil
	31-35	G	grey brown silty clay
	35-50	G	light grey brown fine sand
	50-65		clayey sand, orange nodules, black organic inclusions
	65-85	G	brown fine sand, occasional organics
	85-100	G	grey fine sand, occasional organics, fewer oxidised organics
	100-140		coarse grey brown sand, charcoal band @ 115, some fine gravel
	140	S	gravel

6	0-28		top soil
	28-40	S	grey mottled clayey sandy silt
	40-50	G	grey mottled fine sand
	50-78		light brown fine medium sand
	78-90	G	medium coarse sand
	90-102	G	coarse sand, some fine gravel
	102	S	gravel
8	0-40		top soil
	40-46	G	brown clay occasional organics
	46-52	G	light brown sandy clay, orange nodules, black organic inclusions
	52-104	G	silty sand, bands of grey & brown , occasional organics and roots
	104-150	G	coarse sand, fine gravel
	150	S	gravel
10	0-35		top soil
	35-40	G	grey mottled clayey sandy silt
	40-72	G	clayey silt
	72-74	S	grey brown fine sand
	74-79	S	medium brown fine silty sand
	79-100	G	medium brown fine medium sand
	100-115		coarse sand
	115	S	gravel
12	0-42		top soil
	42-48	G	light brown silty clay, mottled
	48-50	S	uniform light brown clay
	50-69		silty clay, orange/brown nodules 62-64cm
	69-80	G	brown grey clayey silt
	80-85	G	brown grey silty clay
	85-112	G	dark grey clayey silt, sand in bottom 10cm, woody inclusions in 98-100
	112-120	G	coarse sand
	120	S	gravel
14	0-40		top soil
	40-70	S	mottled grey clayey sandy silt
	70-117	G	grey brown silt, organic inclusions, more with depth, some fine sand with depth
	117-122	G	fine silty sand, fine sand laminations
	122-128	G	medium brown fine sand
	128	S	gravel
16	0-43		top soil
	43-46	G	dark brown silty clay
	46-70	G	light brown clay, orange nodules
	70-80	G	silty clay, grey mottled
	80-92	G	clayey silty, grey brown
	92-100	G	grey fine sand, occasional organics
	100-122		clayey sandy silt, increasing sand with depth, occasional organics
	122	S	gravel
18	0-40		top soil
	40-80	S	grey mottled clayey silt, increasing silt content with depth
	80-100	G	medium brown silt, few organic inclusions
	100-120		medium brown fine sand
	120-126	G	fine sand/fine sandy silt laminations (0.5cm)
	126-131	S	medium brown fine sandy silt
20	0-40		top soil
	40-72	G	light brown mottled clay
	72-95	G	grey brown silty clay, reduced mottling with depth

	95-124	G	fine sand, medium brown
	124-138	S	grey brown clayey silt, few organic inclusions
	138	S	gravel
22	0-40		top soil
	40-85	S	grey mottled clayey silt
	85-100	G	grey brown silt, few organics near base
	100-107		medium brown fine silty sand
	107-110	S	red brown medium fine sand
	110-122	S	fine sand
	122-127	S	red brown medium fine sand
	127-143	G	medium brown fine silty sand, sand layer @ 83cm (1cm)
	143-150	G	fine sandy silt, some organic inclusions
	150	S	gravel
24	0-38		top soil
	38-42	G	grey mottled clay
	42-73	G	grey brown clay, some mottling
	73-90	G	dark grey silty clay
	90-110	G	grey brown silty clay, increasing organics with depth
	110-127	G	dark grey sandy silt bands of fine brown sand, occasional organics
	127-131	G	light brown coarse sand
	131-150	G	silty clay, occasional organics
26	0-42		top soil
	42-50	S	grey mottled clayey silt
	50-71		grey mottled silt
	71-100	G	grey brown silt, wood fragment @ 75cm, increasing organics near base
	100-128		medium brown fine silty sand
	128	S	gravel
27	0-118		depth to gravel
27.5	0-112		depth to gravel
28	0-38		top soil
	38-50	S	grey mottled clayey sandy silt
	50-70	G	grey mottled clayey silt
	70-100	G	grey brown silt, some organic inclusions, increasing near base
	100	S	gravel
28.5	0-98		depth to gravel
29	0-70		depth to gravel
30	0-35		depth to gravel

Dovecote Palaeochannel 4 - DC4

Transect 1

Core	Depth	Transition (from above)	Description
0	0-80		depth to gravel
2	0-90		depth to gravel
4	0-90		depth to gravel
6	0-96		depth to gravel
8	0-20		top soil
	20-50	G	medium sand
	50-105		medium sand, coarsening with depth
	105+	S	gravel
10	0-16		top soil
	16-75	G	medium sand

	75-130	G	medium/coarse sand
	130-133	S	fine silty sand
	133-161	S	coarse sand/fine gravel
	161+	S	gravel
12	0-20		top soil
	20-50	G	fine sand
	50-100		orange brown fine sand, grey orange @ 90+
	100-130		medium brown, medium sand
	130-138	S	organic fine silty sand, some organic inclusions
	138-216	S	coarse sand/fine gravel, wood fragment @ 200
	216+	S	gravel
14	0-20		top soil
	20-50	G	medium/fine sand
	50-70		fine sand
	70-100	S	medium brown mottled fine sand, some silt
	100-125		medium sand
	125-130	G	organic fine silty sand
	130-150	S	medium/dark brown medium coarse sand
	150-200		medium/coarse unconsolidated sand
	200-232		medium/coarse sand, charcoal layer @ 207, large wood fragment @ 232
	232-240	S	medium sand
	240+	S	gravel
16	0-20		top soil
	20-50	G	medium sand, fining with depth
	50-100		fine sand, some silt, mottled/organic increase near base
	100-123		organic fine sand, few organic inclusions
	123-130	S	organic fine silty sand, 0.3cm sand layer @ 126
	130-167	S	coarse/medium sand coarsening
	167-175	S	organic fine silty sand, woody fragments, 0.5cm sand layer @ 170
	175-177	S	fine gravel
	177-240	S	coarse/medium sand, woody fragments @ 225, 233
	240+	S	gravel
18	0-20		top soil
	20-45	G	fine sand
	45-90	G	fine silty sand
	90-110	G	medium/fine sand coarsening with depth
	110-120	G	organic fine sand
	120-127	S	medium/coarse sand
	127-130	S	organic fine silty sand
	130-136	S	medium sand
	136-164	G	organic medium sand
	164-177	S	woody fine sandy silt, large wood fragment @ 164
	177-220	S	coarse/medium sand, 1cm silt layer @ 205
	220+	S	gravel
20	0-24		top soil
	24-100	G	medium/fine sand
	100+	S	gravel
19	0-150+		depth to gravel
20.5	0-32		depth to gravel

Transect 2

Core	Depth	Transition (from above)	Description
0	0-24		top soil
	24-72	G	medium orange brown sand
	72	S	gravel
2	0-54		depth to gravel
4	0-58		depth to gravel
5	0-77		depth to gravel
6	0-25		top soil
	25-87	G	medium orange brown sand
	87-100	S	medium brown silty fine sand
	100-106		medium orange brown sand
	106-120	G	coarse sand/fine gravel
	120+	S	gravel
8	0-22		top soil
	22-70	G	red/brown fine sand
	70-87	G	medium sand
	87-100	G	medium/coarse sand
	100-167		coarse medium sand
	167-169	S	large woo fragment
	169-180	S	medium sand some organic inclusions
	180-184	G	medium/coarse sand
	184+	S	gravel
10	0-22		top soil
	22-70	G	silty fine sand, fining with depth
	70-83	G	fine silty sand coarsening with depth, some organic inclusions
	83-95	G	fine/medium sand, some organic inclusions
	95-109	G	coarse/medium sand
	109-131	G	fine/medium sand, wood fragment 117-125
	131-134	S	silty fine sand
	134-137	S	coarse/medium sand
	137-137.5	S	fine sandy silt
	137.5-145	S	medium sand
	145-150	S	organic fine sandy silt, some organic inclusions
	150-200		medium sand, some organic inclusions in lower part, wood fragments 188-194
	200-226	G	medium sand coarsening to fine gravel
	226+	S	gravel
12	0-27		top soil
	27-50	G	fine silty sand
	50-179		organic fine silt, many organic inclusions, mainly woody, small pockets of orange sand near top, wetland macrofossil near base
	179-185	S	medium sand
	185-188	S	gravel stone
	188-217	G	coarse sand/fine gravel
	217-228	S	'missing' unconsolidated medium sand
	228-253	G	dark brown medium sand, wood fragment @ 238
	253+	S	gravel
14	0-16		top soil
	16-29	G	fine sand, some silt
	29-67	G	light grey/ brown mottled fine sandy silt
	67-100	G	organic fine sandy silt, fining downwards, increased organics with depth
	100-167		organic grey brown fine loamy silt, few organic inclusions, debris layer @ 117

	167-168	S	wood fragment
	168-196	S	organic loamy silty, increasing organic fragments to 188 especially wetland, 1cm width dark/light bands, lighter colour below 188
	196	S	wood fragment
	197-212	S	organic loamy silty
	212-222	G	dark brown fine/medium sand
	222+	S	gravel
16	0-16		top soil
	16-30	G	light grey brown fine sandy silt
	30-50	G	grey brown mottled fine sandy silt
	50-77		light orange grey fine sandy silt
	77-83	G	organic grey brown sandy silt
	83-100	S	light orange grey, mottled fine sandy silt
	100-193		fine organic loamy silt, some organic inclusions, wetland and woody
	193-200	S	wood fragment
	200-249		grey brown loamy silt, some woody inclusions, large fragment @ 210
	249+	S	gravel
18	0-27		top soil
	27-50	G	fine sand, some mottling near base
	50-67	G	orange brown fine sandy silt
	67-228	G	medium/light brown fine loamy silt, few woody organic inclusions, 118-125 wetland debris layer, 135-3cm woody layer, wood fragments @ 161, 168, 188
	228	S	boulder clay
20	0-20		top soil
	20-44	G	fine/medium sand
	44-60	S	fine silty sand
	60-70	S	large wood fragment
	70-100	S	uncohesive saturated fine sand, lots of woody inclusions
	100-146	S	very woody uncohesive fine/medium sand, increased cohesiveness with depth
	146-150	S	fine gravel with fine sand matrix
	150+	S	gravel
21	0-76		depth to gravel
21.5	0-34		depth to gravel
22	0-56		depth to gravel
23	0-51		depth to gravel

Transect 3

Core	Depth	Transition (from above)	Description
0	0-38		medium/fine sand top soil
	38+	S	gravel
2	0-36.5		medium/fine sand top soil
	36.5+	S	gravel
4	0-27		top soil
	27-47	G	fine/medium red/brown sand
	47+	S	gravel
6	0-27		top soil
	27-36.5	G	fine/medium red/brown sand
	36.5-46	G	fine gravel in red/brown medium sand matrix
	46+	G	gravel
8	0-26		top soil
	26-88	G	fine/medium red/brown sand
	88+	G	gravel

10	0-26		top soil
	26-81	G	medium red/brown sand
	81-86	G	fine red/brown sand
	86-88	G	coarser medium-light red brown mottled sand
	88-94	S	fine red brown mottled sand
	94-100	G	red brown mottled medium sand coarsens down
	100-111	G	silty fine sand
	111+	S	gravel
12	0-13		top soil
	13-33	G	fine silty red brown sand
	33-46	G	fine red brown sandy silt
	46-70	G	fine silty red brown sand
	70-100	G	fine/medium sand coarsens with depth
	100-108	S	fine sandy silt
	108-123	G	fine/medium sand
	123+	S	gravel
14	0-24		top soil
	24-43	G	medium/fine sand
	43-125	GS	lighter fine/medium sand
	125-131	G	red brown fine sand
	131-134	S	light orange medium/coarse sand
	134-142	G	medium brown fine sand, fining to 142, more silty, incr. organic cont.
	142-150	G	medium brown medium/fine sand
	150-170	G	medium brown medium sand
	170+	S	red boulder clay
16	0-22		top soil
	22-72	G	light grey brown mottled fine sandy silt
	72-78	G	medium brown organic fine sandy silt
	78-100	G	medium sand
	100-105		organic fine sandy silt
	105-130	G	medium brown fine sand, fining to 130, more silty, incr. organic cont.
	130-150	G	medium sand coarsening with depth
	150-172		medium brown silty fine sand
	172-186	S	fine sand with organic inclusions coarsens with depth
	186+	S	gravel
18	0-22		top soil
	22-72	G	light grey brown mottled fine sandy silt
	72-82	G	organic fine sandy silt some mottling
	82-99	G	brown organic fine sandy silt large organic inclusion @ 89 (detritus layer)
	99-100	S	medium sand
	100-123		silty fine sand
	123-143	S	fine/medium sand
	143-160	G	unconsolidated fine sand
	160-172	S	fine sandy silt
	172-187	G	medium sand coarsening
	187+	S	gravel
20	0-34		top soil
	34-80	G	brown fine sandy silt
	80-100	S	organic dark/medium brown fine silty sand, organic inclusions wood @ 88cm
	100-140		organic dark/medium brown fine sandy silt, large no. of organic inclusions
	140-150	G	organic fine silty sand
	150-183	G	fine sand, lower organic content, coarsens with depth
	183+	S	gravel

21.5	0-60		fine silty sand, little evidence of top soil
	60-120	S	organic brown fine sandy silt, large no. of woody organic inclusions, lower organic inclusions with depth
	120-146	G	medium sand
	146+	S	red boulder clay
23.5	0-29		top soil
	29-73	G	fine silty sand
	73-125	S	fine sand coarsening with depth, large wood fragment at 80cm
	125-127	S	fine silty sand
	127-130	G	medium sand
	130-150	G	organic fine sandy silt coarsens with depth
	150+	S	gravel
24.5	0-101		gravel @ 101
25.1	0-120		gravel @ 120
26	0-49		gravel @ 49
30	0-51		gravel @ 51

Transect 4

Core	Depth	Transition (from above)	Description
0	0-30		depth to gravel
2	0-42		depth to gravel
4	0-69		depth to gravel
6	0-84		depth to gravel
7	0-100		depth to gravel
8	0-16		top soil
	16-105	G	medium/brown fine/medium sand
	105+	S	gravel
10	0-20		top soil
	20-50	G	medium brown fine/medium sand
	50-110		medium brown medium sand
	110-120	S	fine/medium sand
	120+	S	gravel
12	0-20		top soil
	20-40	G	fine sand, some silt
	40-50	S	fine/medium mottled sand
	50-113		fine/medium sand, some coarsening with depth, less mottled
	113-117	S	medium/coarse orange sand
	117-125	S	organic fine sandy silt, few organic inclusions
	125-125.5	S	orange fine sand
	125.5-150	S	fine/medium sand, some silt
	150+	S	gravel
14	0-24		top soil
	24-50	G	fine silty sand, fining downwards
	50-75	G	fine sandy silt
	75-82	G	clayey fine sandy silt
	82-88	S	organic medium fine sand
	88-109	S	medium sand
	109-123	S	fine silty sand
	123-163	G	mottled medium sand, few organic fragments
	163-170	G	boulder clay coloured fine/medium sand
	170+	S	gravel
16	0-23		top soil
	23-50	G	silty clay
	50-92	G	medium grey brown mottled medium silt, some clay

	92-111	G	organic fine silt, some fine sand
	111-120	G	medium/coarse sand
	120-124	S	organic fine sandy silt
	124-139	S	medium/coarse sand
	139-141	S	organic fine sandy silt
	141-158	S	fine/medium sand
	158+	S	gravel
18	0-26		top soil
	26-50	G	mottled clayey sandy silt
	50-91		medium silt, increasing organics, reduced mottling with depth
	91-100	S	humified fine sandy silt, some organic fragments
	100-115		peaty dark brown silt
	115-121	G	organic dark brown silt
	121-125	G	medium brown organic loamy silt
	125-129	S	medium sand
	129+	S	boulder clay
20	0-30		top soil
	30-50	G	clayey sandy silt
	50-90	G	medium silt
	90-100	G	humified organic fine sandy silt, some organic fragments
	100-126		medium/dark brown peaty silt
	126-130	S	coarse sand
	130+	S	gravel
21	0-23		top soil
	23-50	G	fine clayey sandy silt
	50-93	G	mottled fine sandy loamy silt
	93-100	S	humified organic fine sandy silt
	100-117	G	organic fine silty sand, coarsening with depth
	117-120	S	organic silt
	120-140	S	medium/fine sand
	140-146	G	fine silty sand
	146-150	G	medium/fine sand
	150+	S	boulder clay
21.5	0-130		depth to gravel
21.51	0-30		depth to gravel
22	0-33		depth to gravel
24	0-10		depth to gravel

Transect 5

Core	Depth	Transition (from above)	Description
0	0-30		top soil
	30-50	G	fine/medium sand- light orange/brown, coarsening with depth
	50+	S	gravel
2	0-20		top soil
	20-68	G	medium orange sand
	68-78	S	coarse sand
	78+	S	gravel
4	0-18		top soil
	18-83	G	medium sand, coarsens with depth
	83-90	S	coarse sand
	90+	S	gravel
6	0-22		top soil
	22-79	S	medium homogenous sand, orange
	79-84	S	grey brown fine sandy silt

	84-100	G	fine silty sand, slight coarsening
	100-102	G	coarse sand, fine gravel
	102+	G	gravel
8	0-19		top soil
	19-75	G	orange medium sand
	75-80	S	grey/brown fine sandy silt
	80-88	G	fine sand
	88-100	G	medium sand, coarsening
	100+	S	gravel
10	0-18		top soil
	18-80	G	medium orange sand
	80-84	G	grey brown fine sandy silt
	84-97	S	fine/medium sand down to medium sand
12	0-13		top soil
	13-70	G	mottled grey brown medium sand
	70-80	S	grey brown fine sand
	80-100	G	grey brown organic fine sandy silt, large no organic inclusions, coarsens with depth
	100-112	G	organic fine sandy silt
	112-150	G	medium sand coarsening
	150+	S	gravel
14	0-20		top soil
	20-34	G	medium sand
	34-97	G	fine silty sand/sandy silt with depth, organic inclusions, fewer in top 30-50
	97-100	G	fibrous peaty sandy silt layer
	100-140	G	organic silt, lots of woody inclusions
	140-144	G	dark grey brown medium/fine sand
	144-155	G	fine sandy silt
	155-161	G	fine sand, small amount of silt
	161-167	S	fine sandy silt, large wood fragment @ 165
	167-200	G	fine/medium sand coarsening
	200-220	G	fine sand
	220+	S	gravel
16	0-23		top soil
	23-50	G	medium/fine orange/brown sand
	50-91	G	light brown fine silt, lots of woody organic inclusions, some roots
	91-100	S	darker brown loamy silt, fibrous organics wetland/woody inclusions
	100-140	G	light brown fibrous peaty silt, quite humified
	140-144	S	'missing' fine sand
	144-187	S	fine sandy silt,. A few organic inclusions
	187+	S	gravel
18	0-15		top soil
	15-50	G	mottled brown/orange fine sand
	50-92	G	fine silty sand incr. silt with depth
	92-123	G	dark grey brown fine sandy silt, lots of organic inclusions
	123-127	S	'missing' fine sand
	127-160	G	fibrous peaty silt
	160-243	G	organic fine loamy silt, manganese/organic, some laminations
	243+	S	gravel
19.5	0-24		top soil
	24-50	G	fine sand
	50-100	G	fine silty sand, a few organics, more with depth, esp. 80-100
	100-187	G	organic fine loamy silt, manganese/organic, some laminations, some organic inclusions, fine sand layer 167-171
21.5	0-43		top soil

	43-50		medium fine sand
	50-84	G	fine silty sand, some organic
	84-125	G	fine sandy silt, large organic content
	125-140	G	fine sand, some silt, high organic content
	140+	S	gravel
22	0-31		gravel @ 31
23.5	0-20		gravel @ 20
24	0-40		gravel @ 40
25.5	0-83		gravel @ 83
27.5	0-97		gravel @ 97

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Transect 1

Core	Depth	Description
1	0-26	depth to gravel
2	0-76	depth to gravel
3	0-57	depth to gravel
4	0-36	depth to gravel
5	0-68	depth to gravel
6	0-44	top soil
	44-47	medium sand
	47-54	grey coarse medium sand
	54	gravel
8	0-36	top soil
	36-62	black peaty silt
	62-71	fine sand with peaty bands
	71-72	peaty fine sand
	72	gravel
9	0-94	depth to gravel
10	0-50	organic silty top soil
	50-70	laminated peaty black silt with medium fine sand
	70-81	medium fine sand, organic band 75cm
	81-93	laminated peaty black silt with medium fine sand
	93-110	unconsolidated medium sand
12	0-30	top soil
	30-60	medium sand
	60-83	medium fine sand with 1cm organic silt bands
	83-112	coarse sand
	112	gravel
14	0-33	top soil
	33-50	medium sand with top soil
	50-67	fine medium sand
	67-85	fine medium sand with 1cm organic silt bands
	85-111	coarse sand
	111	gravel
16	0-31	top soil
	31-50	medium sand with top soil
	50-76	medium fine sand
	76-93	medium fine sand with 1cm organic silt bands
	93-97	coarse sand
	97	gravel
18	0-33	top soil
	33-50	medium sand with top soil
	50-72	fine medium sand with 1cm organic silt bands

	72-76	coarse sand
	76	gravel
20	0-33	top soil
	33-50	medium sand with top soil
	50-60	fine medium sand with 1cm organic silt bands
	60-74	coarse sand
	74	gravel
22	0-31	top soil
	31-55	medium sand with some top soil
	55-64	coarse sand
	64	gravel
24	0-30	top soil
	30-58	medium sand with top soil
	58-61	coarse sand
	61-64	fine sand with frequent charcoal inclusions
	64	gravel
26	0-41	top soil
	41-43	coarse sand
	43-45	fine medium sand
	45-50	medium sand
	50-64	medium sand with fine organic sand bands (1cm)
	64	gravel
28	0-30	top soil
	30-50	medium sand
	50	gravel
30	0-35	top soil
	35-47	medium sand
	47	gravel
33	0-41.5	depth to gravel
36	0-42	depth to gravel

Transect 2

Core	Depth	Description
1	0-8	depth to gravel
2	0-49	depth to gravel
3	0-38	depth to gravel
4	0-37	depth to gravel
5	0-56	depth to gravel
6	0-10	top soil
	10-69	organic silt, frequent organic inclusions
	69-79	medium sand and organic silt layers (<1cm)
	79	gravel
8	0-10	top soil
	10-87	peaty silt, frequent organic inclusions
	87-92	fine medium sand
	92	gravel
10	0-30	peaty top soil
	30-86	peaty silt
	86-100	organic fine medium sand
	100-101	medium sand
	101-114	organic medium fine sand
	114	gravel
12	0-50	peaty top soil
	50-64	dark peaty silt

	64-80	coarse medium sand
	80-121	fine medium sand with 1 cm organic bands
	121-140	organic fine silty sand
	140	gravel
14	0-33	mottled top soil
	33-50	top soil with medium sand, laminated
	50-100	fine medium sand
	100-150	fine medium sand with 1cm organic bands, large peaty bands (with sandy matrix) 105-110 & 120-122
	150	gravel
16	0-30	top soil
	30-50	medium sand with top soil
	50-100	fine medium sand
	100-136	fine medium sand with peaty layers @ 107-110 114-115 128-9 134-136
	136	gravel
18	0-27	top soil
	27-61	medium sand
	61-96	fine medium sand with peaty bands (<1cm)
	96	gravel
19	0-87	depth to gravel
20	0-37	top soil
	73-52	medium sand with some top soil
	52-72	fine medium sand with peaty bands
	72-73	medium sand with freq. charcoal inclusions
	73-75	coarse sand
	75	gravel
22	0-39	top soil
	39-51	medium sand, fine sand layer 45-47
	51	gravel
23	0-51	depth to gravel
24	0-33	top soil
26	0-29	top soil
	29-39	medium sand
	39	gravel
28	0-36	depth to gravel
30	0-32	depth to gravel (bottom 7 cm medium sand)
33	0-35	depth to gravel
36	0-39	depth to gravel

Transect 3

Core	Depth	Description
1	0-15	depth to gravel
2	0-39	depth to gravel
3	0-34	depth to gravel
4	0-24	depth to gravel
5	0-41	depth to gravel
6	0-55	depth to gravel
7	0-24	top soil
	24-50	organic silt, frequent organics
	50-75	medium sand, few organics
	75-85	fine sand, some organic content
	85	gravel
9	0-37	peaty top soil
	37-65	silty organic peat, freq. organics

	65-70	fine sand, some organic content
	70-101	fine peaty organic sand
	101	gravel
11	0-43	peaty top soil
	43-77	peaty silt
	77-95	medium fine sand
	95-110	peaty fine sand, increasing minerogenics with depth
	110	gravel
13	0-77	silty peat, no evidence top soil, frequent organics
	77-82	peaty silt, lighter than above
	82-123	organic peaty silt
	123-140	organic fine sand, some medium sand
15	0-100	peaty silt, frequent organics
	100-120	organic fine medium sand
	120-132	medium sand
	132-133	organic silt
	133-141	medium sand
	141-148	coarse sand
	148	gravel
17	0-40	peaty top soil
	40-80	peaty silt
	80-92	fine medium organic sand
	92-100	organic silt
	100-140	fine medium sand, with organic silt bands @ 106 108 123 128 133 138 140
	140-148	organic fine medium sand
	148	gravel
19	0-43	mottled top soil
	43-50	organic fine sand
	50-144	fine medium sand with organic bands @ 55 63 70 76 80 86-88 105 109 112 120 126 133 136 138
	144-145	gravel
	145	pink boulder clay
21	0-35	mottled top soil
	35-50	fine medium laminated sand
	50-100	fine medium laminated sand, large organic bands @ 26-30, 38-41, many other finer organic laminations
	100-117	unconsolidated fine medium sand
	117	gravel
23	0-28	top soil
	28-39	top soil & medium sand
	39-77	medium sand
	77-90	silty fine sand, organic inclusions
	90	gravel
25	0-38	top soil
	38-40	top soil & medium sand
	40-86	medium sand, 1cm fine sand layer @ 78
	86	gravel
27	0-40	top soil
	40-42	top soil and medium sand
	42-59	medium sand
	59-63	medium sand, lots of charcoal inclusions
	63-71	medium sand
	71-78	organic fine medium sand
	78	gravel
29	0-25	depth to gravel

30	0-28	depth to gravel
31	0-21.5	depth to gravel
32	0-31	depth to gravel
33	0-31	depth to gravel
36	0-31	depth to gravel

Transect 4

Core	**Depth**	**Description**
0	0-15	depth to gravel
1	0-59	depth to gravel
2	0-12	depth to gravel
3	0-7	depth to gravel
4	0-15	depth to gravel
5	0-58	depth to gravel
6	0-30	peaty top soil
	30-40	peaty silt
	40-50	fine sandy peat
	50-77	peaty fine sand
	50-77	depth to gravel
8	0-20	peaty top soil
	20-50	silty peat, some organics
	50-79	peaty silty fine sand, some organics
	79	gravel
10	0-20	peaty stop soil
	20-72	silty peat, black humified layer at 35cm
	72-89	fine sand few organics
	89-107	sharp transition to peaty silt, some organics
	107	depth to gravel
12	0-23	top soil
	23-50	silt, some organics
	50-65	peaty silt, some organics
	65-73	fine sand
	73-100	fine sand with black silty organics bands
	100-106	peaty silt
	106-111	medium sand
	111	depth to gravel
14	0-30	top soil
	30-44	silt, some organics
	44-50	fine sand, some organics
	50-85	fine medium sand, organic silt @ 60 cm
	85-90	silt some organics
	90-103	medium sand
	103	depth to gravel
16	0-27	top soil
	27-35	fine sandy silt, some organics
	35-50	fine medium sand
	50-71	fine medium sand, black horizontal colour bands
	71-88	silt
	88-101	fine medium sand
	101	depth to gravel
18	0-23	top soil
	23-38	mottled clayey fine sandy silt
	38-83	fine medium sand organic silt band @ 67cm
	83-86	silty fine sand

	86-98	medium sand
	98	depth to gravel
20	0-21	top soil
	21-31	clayey fine sandy silt mottled
	31-43	fine sandy silt, some organics
	43-50	fine medium sand
	50-66	silty fine sand, some organics
	66-73	fine medium sand
	73-93	medium fine sand, organic silt bands
	93-100	medium sand
22	0-25	top soil
	25-42	mottled fine sandy silt
	42-48	fine medium sand
	48-50	coarse sand
	50-69	medium coarse sand
	69-76	fine medium sand
	76-98	medium fine sand, bands organic silt
	98	depth to gravel
24	0-30	top soil
	30-38	silty fine sand
	38-89	medium coarse sand
	89	depth to gravel
26	0-24	top soil
	24-36	silty fine sand
	36-69	medium coarse sand
	69-84	medium fine sand, rare organic inclusions
	84	depth to gravel
28	0-22	top soil
	22-36	silty fine sand
	36-62	medium coarse sand
	62-70	medium fine sand, rare organics
	70	depth to gravel
30	0-22	top soil
	22-33	silty fine sand
	33-38	coarse sand
33	31	depth to gravel
36	34	depth to gravel

Transect 5

Core	Depth	Description
0	140	depth to gravel
1	140	depth to gravel
2	133	depth to gravel
3	112	depth to gravel
4	96	depth to gravel
5	0-20	top soil
	20-58	fine sandy silt, some organics
	58-69	peaty silt
	69-74	medium fine sand
	74-99	silty fine sand, some organics
	99	depth to gravel
7	0-30	peaty top soil
	30-50	peaty silt
	50-90	fine sand, bands black organic matter

	90	depth to gravel
9	0-24	peaty top soil
	24-50	peaty silt
	50-85	fine sand, black humified fine sandy bands
	85-89	fine medium sand
	89	depth to gravel
11	0-27	top soil
	27-42	fine sandy silt, mottled
	42-50	fine medium sand
	50-64	medium fine sand. black fine sandy lenses
	64-89	fine sand, organic silt bands
	89	depth to gravel
13	0-20	top soil
	20-38	fine sandy silt, mottled
	38-44	medium sand
	44-54	coarse sand
	54-76	fine sand, medium brown organic silt bands
	76-100	fine sand, black humified organic silt bands
	100	depth to gravel
15	0-30	top soil
	30-38	fine sandy silt, mottled
	38-50	coarse medium sand
	50-75	fine sand, medium brown organic silt bands
	75-97	fine sand, black humified organic silt bands
	97	depth to gravel
17	0-30	top soil
	30-43	mottled fine sandy silt
	43-50	coarse medium sand
	50-60	medium sand
	60-71	fine sand, medium brown organic silt bands
	71-93	fine sand, black humified organic silt bands
	93-97	medium sand
19	0-26	top soil
	26-41	mottled fine sandy silt
	41-50	medium sand
	50-72	fine sand, medium brown organic fine sandy silt bands
	72-99	fine sand, black humified organic silt bands
	99	depth to gravel
21	0-39	top soil
	39-44	mottled fine sandy silt
	44-50	coarse medium sand
	50-77	fine sand, medium brown fine sandy silt bands
	77-83	coarse medium sand
	83-90	black humified, fine sandy silt
	90	depth to gravel
23	0-30	top soil
	30-38	mottled fine sandy silt
	38-75	coarse medium sand
	75-79	organic medium fine sand
	79	depth to gravel
25	0-20	top soil
	20-38	fine sandy silt, mottled
	38-60	coarse medium sand
	60-65	fine sand, few <1cm silt bands
	65-70	silty fine sand, black colour

	70	depth to gravel
27	0-20	top soil
	20-33	organic/mottled fine sandy silt
	33-40	fine medium sand
	40-61	coarse medium sand
29	31	depth to gravel
30	38	depth to gravel
33	38	depth to gravel
36	43	depth to gravel

Kellwood Palaeochannel 1 -KW1

Transect 1

Core	Depth	Description
0	0-26	depth to gravel
1	0-22	depth to gravel
2	0-30	depth to gravel
3	0-11	depth to gravel
4	0-26	depth to gravel
5	0-28	depth to gravel
5.5	0-36	depth to gravel
6	0-83	depth to gravel
7	0-77	depth to gravel
8	0-30	depth to gravel
	30-40	silty medium to fine sand
	40-50	medium sand
	50-79	fine medium sand
10	0-20	top soil
	20-37	fine medium sand
	37-57	silty fine sand, mottled, few organics
	57-80	fine medium sand with sandy organic bands
	80-88	medium coarse sand woody organic bands
	88-126	medium sand, fine sandy organic bands
12	0-10	top soil
	10-30	fine medium sand
	30-50	silty medium fine sand, mottled, few organic inclusions
	50-64	silty medium fine sand, mottled, few organic inclusions
	64-81	fine medium sand, fine sandy organic bands
	81-117	medium coarse sand
	117-137	fine medium sand, organic silty bands
14	0-15	top soil
	15-34	fine medium sand
	34-45	silty medium fine sand, mottled, few organic inclusions
	45-50	fine medium sand, organic silty bands
	50-75	fine medium sand, organic silty bands
	75-155	medium coarse sand
16	0-13	top soil
	13-37	fine medium sand, some organics
	37-57	fine medium sand
	57-77	peaty silt
	77-90	peaty silt, humified
	90-100	peaty fine sandy silt
	100-119	peaty silt, humified at 100cm

	119-137	fine medium sand, organic fine sand bands
	137-155	coarse sand
	155-174	coarse sand, woody and charcoal fragments
18	0-14	top soil
	14-46	fine medium sand
	46-50	peaty, fine sandy silt
	50-62	fine medium sand
	62-80	peaty, fine sandy silt, sandy lenses
	80-150	medium coarse sand, coarsens with depth
	150-200	medium coarse sand, occasional fine sandy lenses
	200-204	coarse sand
20	0-10	top soil
	10-25	fine medium sand
	25-30	medium fine sand
	30-50	fine medium sand
	50-79	coarse medium sand
	79-134	coarse sand
	134-140	coarse medium sand
	140-150	coarse sand and gravel
22	0-10	top soil
	10-30	fine medium sand
	30-50	medium sand
	50-74	medium coarse sand
	74-100	coarse medium sand
	100-133	medium coarse sand
	133	charcoal shards
	133-150	coarse sand and gravel
	150-179	coarse sand and gravel
24	0-10	top soil
	10-32	medium fine sand
	32-50	medium coarse sand
	50-83	coarse sand and gravel
	83	charcoal shards
	83-133	coarse sand
	133	charcoal
	133-153	coarse sand and gravel
26	0-15	top soil
	15-43	medium fine sand
	43-65	coarse sand
	65-73	gravel and coarse sand
	73	charcoal
	73-100	coarse sand
	100-120	gravel and coarse sand
28	0-15	top soil
	15-45	fine medium sand
	45-64	medium sand
	64-90	coarse sand
	90-98	fine medium sand
30	0-17	top soil
	17-44	fine medium sand
	44-76	coarse sand
33	0-75	depth to gravel

36	0-60	depth to gravel

Transect 2

Core	Depth	Description
0	0-30	depth to gravel
1	0-22	depth to gravel
2	0-36	depth to gravel
3	0-47	depth to gravel
4	0-80	depth to gravel
5	0-20	top soil
	20-50	silty medium fine sand
	50-64	fine medium sand
7	0-20	top soil
	20-50	clayey fine sandy silt
	50-70	fine medium sand
	70-89	laminated silty fine sand
9	0-15	top soil
	15-42	silty medium fine sand
	42-50	medium sand
	50-65	fine medium sand, silty fine sands
	65-90	medium sand
	90-100	coarse sand
11	0-10	top soil
	10-29	silty medium fine sand
	29-42	fine medium sand
	42-45	coarse sand
	45-56	fine medium sand
	56-66	medium coarse sand
	66-90	fine medium sand
13	0-15	top soil
	15-44	silty medium fine sand
	44-60	peaty silt
	60-68	medium fine sand, organic silt bands
	68-100	medium coarse sand, organic silty bands
	100-110	coarse sand
15	0-10	top soil
	10-23	silty, medium fine sand
	23-27	medium sand
	27-56	peaty fine sandy silt
	56-66	medium fine sand, peaty silt near top
	66-126	coarse sand
	126-140	medium fine sand
	140-147	coarse sand
17	0-10	top soil
	10-26	fine medium sand
	26-65	fine sandy silt, some organics
	65-100	medium coarse sand
	100-174	coarse sand
19	0-8	top soil
	8-25	fine medium sand
	25-59	fine sandy silt
	59-65	medium coarse sand

	65-75	medium fine sand, organic silt bands
	75-126	medium coarse sand
	126-148	fine medium sand, organic silt and coarse sand bands
	148-150	medium sand
	150-164	medium coarse sand
	164-170	degraded wood
	170-179	coarse sand
21	0-6	top soil
	6-50	medium fine sand
	50-72	medium coarse sand
	72-74	fine medium sand
	74-121	medium coarse sand
	121-136	medium coarse sand, organic lenses
	136-150	medium sand, woody fragments at 140cm
	150-190	coarse sand, wood fragments at 165cm
23	0-10	top soil
	10-42	medium fine sand
	42-50	coarse sand
	50-60	medium fine sand
	60-100	coarse sand, wood at 70cm
	100-127	coarse sand
	127-137	fine medium sand
	137-150	coarse sand, woody debris at 140cm
	150-162	coarse sand
25	0-10	top soil
	10-42	medium fine sand
	42-77	coarse sand
	77-84	coarse medium sand
	84-110	coarse sand
	110-120	coarse medium sand, wood at 110cm
	120-140	coarse sand, wood at 120cm
27	0-10	top soil
	10-42	medium fine sand
	42-50	medium coarse sand
	50-64	coarse medium sand
	64-73	coarse sand
	73-83	coarse medium sand
	83-100	coarse sand
	100-129	coarse sand, fine lens @ 120-122
29	0-8	top soil
	8-42	medium fine sand
	42-50	medium coarse sand
	50-64	fine medium sand
	64-78	medium coarse sand
	78-83	fine medium sand
	83-109	coarse sand
33	0-77	depth to gravel
36	0-72	depth to gravel

Transect 3

Core	Depth	Description
0	0-90	depth to gravel

1	0-60	depth to gravel
2	0-73	depth to gravel
3	0-65	depth to gravel
4	0-25	top soil
	25-40	silty fine sand
	40-54	medium fine sand
	54-64	medium sand
6	0-25	top soil
	25-40	silty fine sand, organic inclusions
	40-50	medium fine sand, laminations
	50-88	medium fine sand, fine sandy layers (<1cm)
8	0-10	top soil
	10-21	orange, fine medium sand
	21-50	peaty silt
	50-60	medium fine sand, organic silty fine sand bands, organic inclusion
10	0-10	top soil
	10-19	orange, fine medium sand
	19-60	peaty silt
	60-64	fine medium sand
	64-93	coarse sand
	93-120	medium fine sand, bands of fine sandy silt
12	0-5	top soil
	5-30	orange fine medium sand
	30-50	peaty silty fine sand
	50-75	peaty silty fine sand
	75-83	medium fine sand, organic silty fine sand bands
	83-116	coarse sand
	116-139	medium fine sand, organic silty fine sand bands
14	0-5	top soil
	5-35	fine medium sand
	35-70	peaty silty fine sand
	70-78	medium fine sand, organic silt fine sand bands
	78-86	peaty silty fine sand
	86-100	coarse sand
	100-137	medium sand, coarsens with depth
	137-150	fine medium sand, organic fine sand bands
	150-163	medium sand
16	0-5	top soil
	5-45	medium sand
	45-50	medium coarse sand
	50-62	fine sand with organic inclusions
	62-83	medium coarse sand
	83-84	fine sand with organic inclusions
	84-127	medium coarse sand
	127-128	organic fine sand
	128-150	medium sand, coarsens with depth
	150-176	medium coarse sand
18	0-5	top soil
	5-35	medium fine sand
	35-50	medium coarse sand
	50-60	fine sand with organic inclusions
	60-74	medium coarse sand

	74-74.5	fine sand
	7405-100	medium coarse sand
	100-113	coarse medium sand
	113-120	fine medium sand with fine sand bands
	120-123	medium fine sand with fine sandy bands
	123-172	coarse sand
20	0-10	top soil
	10-40	coarse medium sand
	40-50	medium coarse sand
	50-62	fine sand with organic inclusions
	62-80	coarse medium sand with occasional fine sand bands
	80-100	fine medium sand with occasional fine sand bands
	100-109	medium coarse sand
	109-110	medium sand with organic inclusion
	110-120	medium coarse sand
	120-132	fine medium sand with organic fine sand bands
	132-152	medium coarse sand
22	0-14	top soil
	14-45	coarse medium sand, charcoal at 40cm
	45-50	coarse sand
	50-60	fine sand with organic inclusions
	60-93	fine medium sand
	93-100	silty fine sand
	100-114	fine medium sand
	114-127	fine medium sand, organic fine sand bands, some organic inclusions
	127-143	medium coarse sand
24	0-8	top soil
	8-38	fine medium sand, charcoal at 35cm
	38-50	medium coarse sand
	50-66	medium fine sand with organic inclusions
	66-90	medium coarse sand
	90-106	medium sand
	106-115	fine medium sand, fine sandy organic bands
	115-123	medium coarse sand, fine sandy organic bands
	123-137	medium coarse sand
26	0-16	top soil
	16-43	fine medium sand
	43-50	medium coarse sand
	50-60	fine medium sand
	60-76	medium coarse sand
	76-100	medium sand
	100-116	coarse sand
28	0-10	top soil
	10-38	fine medium sand
	38-40	medium coarse sand
	40-50	coarse sand
	50-58	medium fine sand
	58-70	medium coarse sand
	70-87	coarse medium sand
	87-102	coarse sand
30	0-13	top soil
	13-40	medium fine sand

	40-50	medium coarse sand
	50-52	medium fine sand
	52-73	medium coarse sand
	73-83	coarse medium sand, bands of fine sand
	83-91	coarse sand
34	0-80	depth to gravel
38	0-70	depth to gravel

Transect 4

Core	Depth	Description
0	0-10	top soil
	10-50	medium fine sand
	50-100	medium fine sand, organic inclusions
	100-150	peaty fine sandy silt
	150-152	peaty fine sand, increasingly peaty with depth
1	0-150	depth to gravel
1.2	0-29	depth to gravel
1.4	0-28	depth to gravel
1.6	0-30	depth to gravel
1.8	0-26	depth to gravel
2	0-28	depth to gravel
2.2	0-30	depth to gravel
2.4	0-28	depth to gravel
2.6	0-30	depth to gravel
2.8	0-32	depth to gravel
3	0-25	depth to gravel
3.2	0-32	depth to gravel
3.4	0-30	depth to gravel
3.6	0-39	depth to gravel
3.8	0-31	depth to gravel
4	0-33	depth to gravel
4.2	0-99	depth to gravel
4.5	0-100	depth to gravel
5	0-14	top soil
	14-22	fine medium sand
	22-50	peaty fine sandy silt
	50-100	silty medium fine sand, thin organic silt layers
	100-115	silty medium fine sand
7	0-5	top soil
	5-12	fine medium sand
	12-72	peaty silt
	72-80	medium fine sand, organic lenses
	80-88	peaty silt
	88-100	silty fine sand with organic lenses
9	0-5	top soil
	5-24	fine medium sand
	24-50	peaty silt, increasing silt with depth
	50-73	peaty silt, more fibrous with depth
	73-78	fine medium sand
	78-125	fine sandy silt
	125-135	fine medium sand
11	0-5	top soil

	5-36	medium sand
	36-50	peaty silt
	50-78	peaty silt, with fine sand lenses
	78-172	coarse sand
13	0-25	top soil
	25-50	fine sandy silt, occasional organic inclusions
	50-78	silty, medium fine sand
	78-202	coarse sand
15	0-5	top soil
	5-43	fine medium sand
	43-72	coarse sand
	72-74	medium fine sand
	74-133	coarse sand
	133-164	medium coarse sand
	164-168	wood fragment
	168-200	coarse sand
17	0-9	top soil
	9-37	fine medium sand
	37-50	coarse sand
	50-90	coarse medium sand
	90-91	woody band
	91-100	coarse medium sand
	100-130	medium sand, silty fibrous peaty lenses
	130-150	coarse sand, silty fibrous peaty lenses
	150-188	coarse sand
19	0-8	top soil
	8-41	fine medium sand
	41-50	coarse sand
	50-65	medium fine sand
	65-72	medium sand, organic and maganese inclusions
	72-100	medium coarse sand
	100-119	medium sand
	119-126	coarse sand
	126-134	medium coarse sand with organic inclusions
	134-170	coarse sand
21	0-9	top soil
	9-39	fine medium sand
	39-50	coarse sand
	50-60	fine medium sand
	60-100	medium coarse sand
	100-117	fine medium sand, fine sand laminations
	117-150	coarse sand
23	0-9	top soil
	9-39	fine medium sand
	39-50	coarse sand
	50-64	fine medium sand
	64-100	medium coarse sand
	100-126	coarse sand
25	0-8	top soil
	8-34	fine medium sand
	34-50	coarse sand
	50-60	fine medium sand

	60-96	medium coarse sand
	96-100	coarse sand
27	0-102	depth to gravel
29	0-94	depth to gravel
33	0-78	depth to gravel
36	0-71	depth to gravel

Transect 5

Core	Depth	Description
1	0-138	depth to gravel
2	0-104	depth to gravel
3	0-105	depth to gravel
4	0-105	depth to gravel
5	0-100	depth to gravel
6	0-10	top soil
	10-25	fine medium sand
	25-83	medium fine sand, organic silt bands
	83-100	fine medium sand
	100-130	peaty fine sandy silt, wood at 125cm
8	0-5	top soil
	5-25	fine medium sand
	25-64	peaty fine sandy silt, frequent organic inclusion
	64-85	medium fine sand, organic silt band
	85-92	fine sandy silt, some organic inclusions
10	0-6	top soil
	6-28	fine medium sand
	28-61	peaty fine sandy silt
	61-71	fine medium sand
	71-80	peaty silt
	80-90	fine medium sand
12	0-16	top soil
	16-29	fine medium sand
	29-50	fine sandy silt
	50-59	fine sandy silt organic inclusions
	59-95	peaty silty fine sand
	95-100	coarse medium sand with silty organic bands
	100-115	fine medium sand
14	0-10	top soil
	10-45	fine medium sand
	45-72	fine sandy silt, mottled, some organic inclusions
	72-100	fine medium sand, organic silt bands, coarsens downwards
	100-150	medium coarse sand, animal burrow
	150-157	medium coarse sand
16	0-15	top soil
	15-30	fine medium sand
	30-150	medium coarse sand
	150-170	coarse sand, lots of woody fragments
	170-182	medium coarse sand, lots of woody fragments
18	0-14	top soil
	14-40	fine medium sand
	40-50	medium coarse sand
	50-100	medium coarse sand, coarsens with depth

	100-150	coarse sand
	150-200	medium coarse sand, coarse bands at 176 and 190cm
	200-201	coarse sand
20	0-15	top soil
	15-40	fine medium sand
	40-50	medium coarse sand
	50-100	fine medium sand, charcoal at 95cm
	100-125	fine medium sand
	125-135	fine medium sand, organic silty bands
	135-187	medium coarse sand
22	0-14	top soil
	14-41	fine medium sand
	41-50	medium coarse sand
	50-65	medium coarse sand, charcoal at 65cm
	65-133	coarse sand
	133-142	peaty fine sand, sand layer at 138-140cm
	142-150	medium coarse sand
	150-182	coarse sand
24	0-10	top soil
	10-42	medium coarse sand
	42-76	coarse sand
	76-86	coarse sand and fine gravel
	86-170	coarse sand
	170-180	coarse sand and fine gravel
26	0-9	top soil
	9-41	fine medium sand
	41-50	medium coarse sand
	50-90	medium coarse sand, organic fine sandy bands
	90-100	coarse sand, organic band at 90cm +
	100-116	coarse sand, organic fine sand bands
	116-126	coarse sand and fine gravel
28	0-14	top soil
	14-46	fine medium sand
	46-50	coarse sand
	50-100	medium coarse sand
	100-110	coarse sand
30	0-14	top soil
	14-44	fine medium sand
	44-50	medium coarse sand
	50-100	coarse sand
33	0-87	depth to gravel
36	0-78	depth to gravel

Kellwood Palaeochannel 2 -KW2

Transect 1

Core	Depth	Other
0	7	depth to gravel
0.5	38	depth to gravel
1	30	depth to gravel
2	38	depth to gravel

3	23	depth to gravel
5	0-50	peaty top soil
	50-150	clayey silt some organic inclusions
	150-191	medium coarse sand
	191-196	coarse sand
7	0-33	top soil
	33-85	clayey silt with organic inclusions
	85-92	silty fine sand
	92-100	fine medium sand
	100-150	medium coarse sand
	150-157	coarse sand
9	0-22	peaty top soil
	22-50	peaty clayey silt
	50-92	peaty silt
	92-100	fine medium sand
	100-133	medium coarse sand
11	0-37	peaty top soil
	37-50	peaty clayey silt
	50-107	peaty silt
	107-115	medium coarse sand
13	0-32	peaty top soil
	32-100	peaty clayey silt
	100-115	medium coarse sand
15	0-34	peaty top soil
	34-50	peaty clayey silt
	50-94	peaty silt
	94-100	medium sand
	100-132	medium coarse sand
17	0-24	top soil
	24-50	fine medium sand
	50-73	medium sand with silty fine sand lenses
	73-93	coarse sand with fine sand lenses
	93-100	medium sand
	100-117	medium coarse sand, woody fragments at base
19	0-18	top soil
	18-50	fine medium sand
	50-76	medium sand
	76-100	coarse medium sand
	100-113	medium coarse sand
	113-135	coarse sand
	135-150	medium coarse sand
	150-173	coarse sand
21	0-20	top soil
	20-83	fine medium sand
	83-112	coarse medium sand
	112-150	medium sand
	150-170	medium coarse sand, woody inclusions at base
23	0-19	top soil
	19-86	fine medium sand
	86-122	coarse medium sand
	122-134	coarse sand

	134-150	medium coarse sand, some woody fragments
	150-196	medium sand
25	0-21	top soil
	21-50	medium fine sand
	50-85	medium sand
	85-100	coarse sand
	100-150	medium coarse sand
	150-200	coarse sand
27	0-25	top soil
	25-50	medium fine sand
	50-100	medium sand
	100-110	coarse medium sand
	110-140	medium coarse sand
	140-176	coarse sand
27	200	depth to gravel
30	132	depth to gravel

KW2 Transect 2

Core	Depth	Description
0	0-3	depth to gravel
0.6	0-18	depth to gravel
1	0-6	depth to gravel
1.5	0-9	depth to gravel
2	0-110	depth to gravel
3	0-24	peaty top soil
	24-50	silty clay some organic inclusions
	50-96	peaty clayey silt with sand lenses near 90cm
	96-100	medium and coarse sand
	100-150	medium coarse sand with fine sand organic lenses
	150-180	fine sand organic lenses
	180-194	coarse sand matrix
	194-200	weathered bedrock
5	0-35	top soil
	35-50	silty clay with some organic inclusions
	50-110	peaty clayey silt
	110-150	peaty clayey silt occasional fine sand bands
	150-195	coarse sand
7	0-50	top soil
	50-100	peaty silty with woody fragments
	100-138	peaty silt
	138-150	coarse sand
	150-197	coarse sand
9	0-50	top soil, fibrous at top
	50-100	peaty silt
	100-123	peaty silt, humified in top 10cm
	123-150	coarse sand
	150-167	coarse sand
11	0-14	top soil with organic inclusions
	14-50	clayey silt with organic inclusions
	50-100	peaty clayey silt, sand layers @ 78 and 80
	100-143	coarse sand, freq. fine sand & woody layers

	143-150	coarse sand
	150-165	coarse sand
13	0-19	top soil
	19-50	clayey silty fine sand
	50-75	fine sand with silty fine sand bands
	75-176	coarse sand
15	0-22	top soil
	22-50	clayey fine medium sand
	50-86	medium sand
	86-100	medium coarse sand
	100-141	coarse sand
	141-150	medium coarse sand
	150-175	coarse medium sand
	175-194	coarse sand frequent woody fragments
17	0-15	top soil
	15-50	fine medium sand
	50-100	medium sand
	100-139	medium sand
	139-150	coarse medium sand
	150-178	medium coarse sand
	178-200	coarse sand with woody fragments
	200-209	coarse sand
19	0-32	top soil
	32-50	fine medium sand
	50-100	medium sand
	100-150	silty medium sand
	150-172	medium sand
	172-196	coarse sand with woody fragments
21	0-164	depth to gravel
23	0-28	top soil
	28-50	fine medium sand
	50-100	medium sand
	100-131	coarse medium sand
	131-150	coarse sand
	150-163	coarse sand, organic inclusions/bands
25	0-151	depth to gravel
27	0-186	depth to gravel
30	0-187	depth to gravel

Transect 3

Core	Depth	Description
0	5	depth to gravel
1	132	depth to gravel
2	0-20	top soil
	20-38	clayey silt
	38-50	fine sandy clayey silt
	50-100	clayey fine medium sand, few organic inclusions
	100-150	fine medium sand, bands of finer material and organic inclusions
	150-164	medium sand
4	0-50	peaty silt

	50-100	peaty silt
	100-113	peaty silt
	113-142	coarse sand coarsens with depth
6	0-50	peaty clayey silt
	50-100	peaty silt
	100-137	peaty silt
	137-138	coarse sand
8	0-50	peaty clayey silt
	50-90	silt with organic inclusions
	90-95	clayey silt
	95-100	coarse sand
	100-136	coarse sand
10	0-20	peaty silt
	20-50	silty clay with organic inclusions
	50-100	clayey silt
	100-125	peaty silt
	125-134	coarse sand
12	0-22	peaty top soil
	22-50	grey silty clayey with organic inclusions
	50-71	peaty clayey silt, increasing silt with depth
	71-80	medium sand
	80-100	coarse sand
	100-135	coarse sand
14	0-18	top soil
	18-50	grey clayey fine sand
	50-100	reddy medium sand
	100-135	fine sand
	135-150	medium sand
	150-159	coarse sand
16	0-17	top soil
	17-50	mottled fine medium sand
	50-73	medium sand
	73-100	coarse medium sand
	100-148	coarse sand
18	0-18	top soil
	18-50	orange/mottled fine medium sand
	50-86	reddy medium sand
	86-100	reddy medium coarse sand
	100-145	coarse sand, 125cm organic inclusions
20	0-19	top soil
	19-50	fine medium sand
	50-72	medium sand
	72-100	medium coarse sand
	100-130	coarse sand
	130-150	medium sand with fine sand organic bands
	150-164	coarse sand
22	0-23	top soil
	23-70	fine medium sand, charcoal @ 23cm
	70-79	medium coarse sand
	79-100	medium sand
	100-115	medium sand

	115-150	medium sand, fine sandy silt organic bands
	150-177	coarse sand
	177-200	medium sand
	200-211	coarse sand
24	0-22	top soil
	22-50	fine medium sand
	50-86	medium sand
	86-109	medium coarse sand
	109-150	medium sand, fine sandy silt bands 109-129cm
	150-200	coarse sand, occasional silt bands
	200-233	coarse sand
26	0-20	top soil
	20-68	fine medium sand
	68-88	medium sand
	88-124	medium coarse sand
	124-150	medium sand fine sandy silt bands
	150-200	medium sand fine sandy silt bands
	200-250	coarse medium sand, some organic inclusions, fine sandy silt bands coarsens with depth
	250-279	coarse sand, fine sandy silt bands
28	279	depth to gravel
30	192	depth to gravel

Transect 4

Core	Depth	Description
0	17	depth to gravel
1	29	depth to gravel
2	18	depth to gravel
2.5	126	depth to gravel
3	0-30	top soil
	30-50	mottled clayey fine sandy silt
	50-100	fine sandy clayey silt, increasing silt upwards, some organic inclusions
	100-120	fine sandy clayey silt
	120-121	medium sand
	121-130	fine sandy silt, woody inclusions
	130-150	medium coarse sand
5	0-19	top soil
	19-50	mottled clayey silt
	50-67	clayey silt some organic inclusions
	67-90	clayey silt, oxidised organic matter
	90-100	clayey silt, woody inclusions
	100-123	clayey silt
	123-160	medium coarse sand
	160-174	coarse sand
7	0-13	peaty top soil
	13-25	oxidised clayey silt
	25-50	peaty clayey silt
	50-80	peaty silt
	80-100	medium coarse sand
	100-150	medium coarse sand
	150-160	coarse sand

9	0-20	peaty top soil
	20-37	peaty silty clay
	37-78	peaty clayey silt
	78-118	coarse sand
11	0-50	peaty clayey silt
	50-70	peaty silt
	70-100	coarse sand
13	0-20	peaty top soil
	20-50	peaty clayey silt
	50-100	medium coarse sand, coarsens down, few woody fragments
15	0-10	peaty top soil
	10-39	peaty silt
	39-50	medium coarse sand
	50-85	medium coarse sand
17	0-20	top soil
	20-37	mottled silty clay
	37-50	medium sand
	50-81	coarse sand
19	0-15	top soil
	15-30	mottled fine sandy silt
	30-50	grey medium sand
	50-117	coarse sand
21	0-18	top soil
	18-27	mottled fine sandy silt
	27-70	grey medium sand
	70-80	medium sand, organic silty layers
	80-100	coarse sand, organic silty layers
	100-117	medium coarse sand, woody fragments at 103cm
23	0-18	top soil
	18-28	mottled fine sandy silt
	28-50	medium sand
	50-100	medium coarse sand, coarsens with depth
	100-114	coarse sand with woody fragments
25	0-18	top soil
	18-32	mottled fine sandy silt
	32-50	medium sand
	50-100	medium coarse sand, some woody fragments at 77cm
	100-143	some woody fragments at 108, 118cm
27	0-20	top soil
	20-50	fine medium sand
	50-85	medium sand
	85-100	medium coarse sand, woody inclusions
	100-150	coarse sand, charcoal layer at 130cm
	150-151	coarse sand
29	0-19	top soil
	19-50	fine medium sand
	50-100	medium sand, woody organic fragments @ 100
	100-120	medium sand, organic silt bands
	120-200	medium coarse sand
	200-250	coarse sand
31	0-18	top soil

	18-50	fine medium sand
	50-100	medium sand
	100-150	medium coarse sand
	150-190	coarse sand
36	270	depth to gravel

Transect 5

Core	**Depth**	**Description**
0	52	depth to gravel
1	7	depth to gravel
2	18	depth to gravel
2.5	42	depth to gravel
3	0-30	top soil
	30-39	clayey fine sand (laminations)
	39-75	fine sandy clayey silt with organic inclusions
	75-90	medium sand
	90-150	coarse sand
	150-185	coarse sand, gravel layer @ 185
	185-200	coarse sand
	200-220	coarse sand-red @220cm
5	0-15	peaty top soil
	15-50	peaty clayey silt
	50-100	peaty silt with lots of wood
	100-117	peaty silt
	117-147	coarse sand
	147-150	peaty silt (contamination?)
	150-175	coarse sand
	175-200	coarse sand, armoured?
	200-227	coarse sand, large clast @ 200cm
7	0-50	peaty silty fine sand
	50-100	peaty silt, large wood fragments
	100-150	peaty silt, humified in bottom 10cm
9	0-50	peaty silty top soil
	50-100	peaty silt
	100-130	peaty silt, fewer organics in bottom 15cm
	130-143	coarse sand with occasional organic inclusions
11	0-40	fibrous silty peat
	40-50	peaty silt
	50-100	peaty silt, large wood fragments
	100-123	peaty silt
	123-160	coarse sand
13	0-15	peaty top soil
	15-50	peaty silt with large wood fragments
	50-70	peaty silt
	70-80	medium sand with organic inclusions
	80-100	coarse sand
	100-168	coarse sand with woody fragments
15	0-10	top soil
	10-60	fine medium sand
	60-100	medium sand
	100-133	medium coarse sand

	133-191	coarse sand
17	0-20	top soil
	20-50	fine medium sand
	50-127	medium sand
	127-150	coarse medium sand
	150-188	coarse medium sand, some fine sand lenses
	188-200	medium coarse sand
	200-244	medium coarse sand, some large wood fragments
19	0-19	top soil
	19-92	fine medium sand
	92-127	medium fine sand with some silt
	127-200	coarse medium sand
	200-219	coarse sand
21	0-20	top soil
	20-100	fine medium sand
	100-173	fine medium sand with some silt
	173-200	medium coarse sand
	200-209	coarse sand
23	0-20	top soil
	20-50	fine medium sand
	50-100	fine medium sand, coarsens with depth
	100-120	medium sand
	120-150	medium coarse sand
	150-162	coarse sand
25	0-20	top soil
	20-50	fine medium sand
	50-89	medium sand
	89-100	coarse sand
	100-150	medium coarse sand
	150-166	coarse sand
27	0-23	top soil
	23-50	medium coarse sand
	50-114	medium sand, coarsens with depth
	114-150	medium coarse sand
	150-179	coarse sand
30	0-20	top soil
	20-95	fine medium sand
	95-100	medium coarse sand
	100-161	coarse sand